EXPERIMENTAL STUDY OF DYNAMIC BEHAVIOR OF SILICA GEL BED

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CERTIFICATE

This is to certify that the work entitled "EXPERIMENTAL STUDY OF DYNAMIC BEHAVIOUR OF SILICA GEL BED " by Hemant Priyadarshy is a record of work carried out under my supervision and has not been submitted elsewhere for a degree.

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(Hemant Priyadarshy)

CONTENTS

ABSTRACT

An experimental set-up was fabricated in the laboratory to study the regeneration of silica gel bed using electric heating and dehumidification of moist air using the same bed. Experiments were conducted under different set of values of wet-bulb temperature of inlet air and different thicknesses of silica gel beds. The bed thicknesses were kept at 101.6 mm, 177.8 mm and 254 mm. The inlet air wet-bulb temperature was kept at 301K (R.H.= 46.8%),303K (R.H. = 55.9%) and 307K (R.H.=76.2%) while the inlet dry-bulb temperature was kept at 311K and air flow velocity through the bed was maintained at 0.9m/s. The outlet specific humidity was measured at regular intervals of one minute each to get the values of important parameters like break point time, saturation time of the bed and the regeneration time of the bed under varying conditions. Finally correlations for these parameters were obtained in terms of relative humidity of inlet air and the bed thickness.

CHAPTER 1

INTRODUCTION

1.1 DESCRIPTION

None of us can turn a blind eye to the important problems like energy crisis and air-pollution,ozone layer depletion and global warming. Already pinches of these problems have started inflicting adverse effects leading to serious thinking towards the use of alternative energy sources, curbing inefficient use of thermal power plants, automobiles etc.

When seen in this light and the high cost of electrical energy, efforts are on to develop alternate methods of comfort conditioning. Evaporative cooling for human comfort and commercial applications is one of the methods in this endeavor. Use of desert coolers, based on evaporative cooling, has become the cheaper alternate choice for maintaining reasonable comfort conditions in residential buildings, offices, shops, business establishments, theaters, warehouses etc.

Though the ASHRAE chart [1] exhibits 294 K as the effective temperature for human comfort for summer conditions, the involvement of cost factors have led to the use of higher ET of a value of 299 K, causing considerable saving in energy and simplification in the system design. Moreover for the tropical countries like India the effective temperature may be kept even higher in order to save energy. Such system is not only much cheaper than conventional machines, but consumes less electrical energy as well, in addition to less thermal shock to human body during outside movement [3]. Interestingly, the choice of a higher

ET also enables the use of evaporative cooling for air-conditioning.

Though evaporative cooling is, on one hand, advantageous and is gaining wide public preference over the existing systems, its performance proves to be quite ineffective in presence of higher relative humidity in the environment. Thus, it is not suitable for coastal areas, and in the rainy season. For such situations, it has been reported by many researchers in the recent past that the removal of moisture from air using desiccant, followed by sensible and evaporative cooling of the air has a promising prospect in the area of air-conditioning. The use of adsorbent for moisture removal has become an alternate choice in view of increasing energy cost and accompanying demands for energy conservation .

1.2 REVIEW OF PREVIOUS WORK

Many researchers are working in the area of dehumidification using sorbent materials. Some important contributions are mentioned here.

A complete theoretical study of isothermal adsorbent bed has been done by Hougen and Marshall [4] using linear equilibrium relationship between adsorbate content of the gas and of the solid The governing equations have been solved and the results have been presented in a graphical form.

Threlkeld [5] has given equilibrium curves for sorbent materials and put forth the governing equations for isothermal and adiabatic stationary beds. Solutions of these equations can be obtained if variables controlling the performance are known.

Ross and Mclaughlin [6] have presented a method for predicting characteristics of a dynamic adsorbent system. They

have carried out 24 tests in all for adsorption and regeneration, for axial flow of air through the round bed having 6-16 mesh size silica gel. They have found out the effect of inlet air temperature, inlet relative humidity, face velocity and bed thickness.

Olsen [7] has tried to investigate the potential for application of solar energy in warm climates.His report treats various modes of application of both liquid and solid desiccants for space cooling. A special attention is given to regeneration of adsorbent using direct solar radiation.

Prasad and Kumar [8] have studied dehumidification processes under cooled and adiabatic bed conditions for round and tray type beds using Copper Sulphate, Calcium Chloride, and silica gel as adsorbents. Out of these three, silica gel was found to be most suitable for dehumidification. The time for its regeneration using flat plate collector was found to be three hours as compared to one hour of humidification period.

Amero *et. al.* [9] have studied the effect of fluid temperature, pressure, and composition on the performance of drying units using granular desiccants. They have outlined steps involved in designing a drying unit, with special attention to a generalized method for calculating pressure drop.

Rheinfelder [10] has studied the viability of an open cycle adsorption system for solar cooling using an adiabatic column with a solid adsorbent and an external heat-exchanger. Experimental investigations, on a column of silica gel, have been carried out along with the computer simulation of the complete system. Due to the heat-exchanger having a large effect on the efficiency of the system, different types of heat-exchangers were examined. Results

show that compact and simple adsorption column can be successfully used in open cycle adsorbing system and that high enough temperature can be reached using solar collector of simple construction, for regeneration of the adsorbent material.

Ismail *et. al.* [11] have carried out experiment on a simple to build solar-regenerated open cycle grain cooling system. Collier *et.al.*[12] have represented in a paper, a review of thermodynamics of three desiccant cooling cycles-the ventilation cycle, the recirculation cycle and the Dunkel cycle. For the ventilation cycle, quantitative effects of effectiveness of various components were analyzed and it was concluded that

*COPs greater than 1.0, for desiccant cooling system are possible if component performances can be improved.

*Heat- exchanger performance has great influence on the COP.

*Increasing the effectiveness of the evaporative coolers in the system has little effect on the COP.

Jurinak and Mitchell[13] have evaluated the performance of open cycle desiccant air-conditioner for residential application Performance of these systems is compared to the vapor compression machines on the basis of primary energy use and the cost. They have reported that systems with improved dehumidifiers can achieve seasonal COP of the order of 1.1.

Einstein *et.al.*[14] have applied a simple algebraic model of wave motion arising out in the adiabatic fixed- bed desiccant dehumidification of an air stream to the prediction of performance potential of a desiccant air-conditioning system. They have also examined the response of cooling system performance to external process conditions.

Kim, *et.al.* [15] have conducted bench scale tests of a

laminar flow Silica gel packing element. Packing is based on a coated sheet covered with a single layer of 0.25mm Silica gel particles having narrow passage width of 1.46-3.75 mm. Adsorption and regeneration tests were performed for fixed inlet conditions and a uniform initial bed condition. Measured outlet air moisture content and air temperature were compared with theoretical prediction and reasonable agreement was obtained.

1.3 PRESENT WORK

Present work involves the fabrication and installation of experimental set-up, and experimental study of dynamic behavior of silica gel bed. Ambient air was heated and humidified to simulate the ambient conditions of the coastal areas. Parameters of inlet air (before entry to the silica gel bed) namely the dry bulb temperature and wet -bulb temperatures were measured

Air is forced through the silica gel beds of varying thicknesses (Particle size 6.25mm-10mm), Parameters of outlet air viz. wet bulb temperature and dry bulb temperatures were measured at periodic intervals This study was done for adiabatic as well as for cooled beds The behavior of silica gel was studied in two modes:

(1) **Dehumidification Mode** : Hot and humid air was passed through regenerated and cooled (cooled to ambient temperature)beds of silica gel and measurements were made for the relevant parameters.

(2) **Regeneration Mode** : Hot and humid air (simulated conditions)was further heated by means of electrical duct heaters, hot air passed through the saturated beds of Silica Gel, and measurements performed.

CHAPTER 2

COOLING AND DEHUMIDIFICATION PROCESSES

2.1 EVAPORATIVE COOLING

The cooling and humidification of space is a form of air-conditioning that has been recently recognized as an important simple device for comfort cooling. Even though the cooling efficiency is not comparable to that of a mechanical cooling system, it does provide comfort conditions quite conducive to efficient working of human beings under hot and dry weather conditions.

Among many cooling processes the evaporative cooling is most commonly used for various applications where the relative humidity or dry bulb temperature is to be controlled. When water comes in contact with the ambient air, cooling of water and/ or air takes place depending upon the combined effect of the following processes which differ physically from each other :

a. Surface evaporation of water and transfer of latent heat from water.

b. Sensible heat transfer by conduction and convection

c. Heat transfer by radiation .

Heat transfer by radiation is important only in the case of large open areas. In cooling devices, fortunately, this effect is generally insignificant and ignored. On the other hand, the heat transfer by evaporation dominates between the processes a and b. Hence it is customary to call cooling of water and/or air as evaporative cooling However, the amount of moisture present in

the air is the controlling factor in achievement of cooling.

2.1.1 LIMIT OF DIRECT EVAPORATIVE COOLING

The upper limit of sensible cooling achieved by evaporative method is limited by the saturation state of the air leaving the humidifier. However, this state of air may be comfortable only if the effective temperature (ET) for the leaving air is below 293 K [1]. In case of higher Te ,(>293 K) the relative humidity of air beyond 75% is hardly recommended for comfort conditioning It , therefore, implies that the evaporative cooling is not effective in hot ,humid coastal regions and other areas in the monsoon season. Under such situations, the utilization of evaporative cooling technique will call for dehumidification and sensible cooling before humidification of the air. By this method, a lower temperature having humidity within the tolerable limits may be achieved. It means that dehumidification will be a controlling factor for exploitation of this technique.

2.2 DEHUMIDIFICATION

Dehumidification is the reduction of the water vapour content of air . The degree of dehumidification required varies greatly with different applications, and is one of the prime considerations influencing the choice of a method. Within the past decade drying of gases has become an increasingly important operation. Some of the more important commercial applications include:

i. Independent humidity control in air- conditioned spaces-comfort air- conditioning generally requires the maintenance of summer temperature between 297 K and 299 K

and relative -humidity between 45% to55%. The maintenance of these conditions with refrigeration systems is quite expensive and consumes too much of electrical energy There are many cases (e.g. assembly halls, restaurants, large buildings or hotels situated in high humidity areas) in in which the latent heat load is larger than the sensible heat load, where the use of sorption system in conjunction with refrigeration systems will give optimum results.

ii. Lowering of the relative humidity to facilitate handling of hygroscopic materials.

iii. Drying air for the wind tunnels.

iv. Dehydrating natural gas.

v. Providing protective atmosphere for the heat treatment of metals.

vi. Maintaining controlled humidity conditions in warehouses for storage.

vii. Drying of gases which are to be liquefied.

viii. Manufacture of drug and chemicals.

ix. Assembly of motors and transformers.

x. Manufacture of electronic components such as transistors and micro-wave components.

2.2.1 METHODS OF DEHUMIDIFICATION AND THEIR LIMITATIONS

There are several ways to dehumidify the moist air . Some of the commonly used methods are described in detail.

1. CHILLING

In this process, we cool the air below it's dew-point temperature with the help of cooling coils. THe process is

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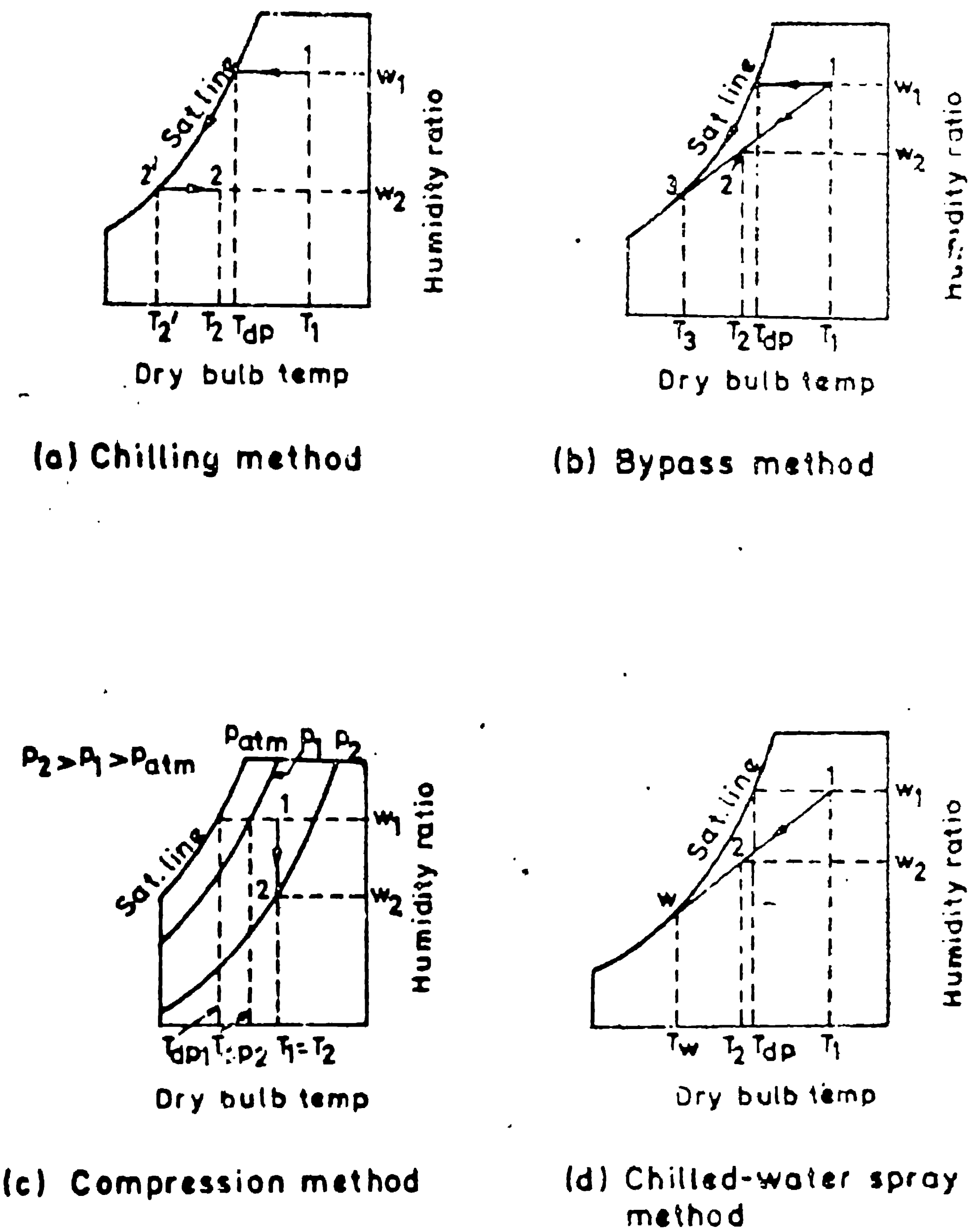


(a) Chilling method

(b) Bypass method

(c) Compression method

(d) Chilled-water spray method

FIG. 2·1 DEHUMIDIFICATION BY VARIOUS METHODS

explained in fig.2.1(a). State-1 shows the inlet air condition and state 2 is the desired condition. The air is first cooled to a temperature T_2 ,by cooling coils, which is less than the dew-point temperature of inlet air.,T_{dp}.Points-2' and 2 are having same moisture level. The air at state -2' is then heated to reach the final state-2.

This process is obsolete ,though ,quite effective as it involves unnecessary cooling and heating. This wastage of energy is generally overcome with the help of well known by-pass method, shown in Fig 2.1(b).In this method, only a part of the ambient air is cooled by the cooling coils up to the temperature T_3 ($<T_{dp}$) and then mixed with the ambient air in a proportion such that the desired state-2 is achieved. The by-pass method ,cannot ,always be used because of the following constraints:

(a) The line joining the inlet state -1 and the desired condition should meet the saturation curve.

(b) The temperature T_3 as shown in Fig.2.1(b) should not be less than the freezing temperature of water.

2. COMPRESSION

When an air-water vapour mixture is compressed, its ability to hold water is decreased, simultaneously the water vapour starts condensing at higher temperature, and dew point of the mixture at elevated pressure becomes higher than the dew point at atmospheric pressure. This process can be explained with the help of Fig. 2.1(c).

. Ambient air has been shown by state-1 having humidity ratio W_1. Its dew point temperature at atmospheric pressure is T_{dp1}.For pressure p_1($p_1>p_{atm}$) its dew point temperature becomes T_{dp2}. At

this pressure , the humidity ratio is not reduced. If the air is compressed further , the water vapour starts condensing . At pressure $p_2(>p_1)$, the dew point rises up to T_{dp2} and the humidity ratio is reduced to W_2. The final state is shown by point-2.

It is ,however, a costly process because of the use of a compressor. The system could be economical where high pressure is required.

3. EVAPORATIVE COOLING WITH CHILLED WATER SPRAY

If the chilled water, having temperature less than the dew point temperature of air, is sprayed in an evaporative cooling system ,the outgoing air will be cooled and dehumidified.

If the inlet air condition is at state 1, the desired condition 2 can be achieved by spraying water at a temperature $T_w(<T_{dp})$, as shown in the Fig. 2.1(d). The drawback of the system lies in the fact that it needs chilled water ,necessitating the use of some sort of refrigeration system. Also, the choice of the desired state of the exit air is restricted to points lying on the line joining the inlet state and the final state such that this line cuts the saturation line on the Psychrometric chart.

4. SORBENT MATERIALS

Desiccants are solid or liquid materials which have the property of extracting and holding other substances (gases or vapour e.g water vapour) brought into contact with them. The sorption process always liberates heat, the major part of which is due to condensation of water vapour. Weight of water vapour held by the substance will increase or decrease depending upon whether the vapour pressure of water vapour held by the substance is less or greater, respectively than the partial pressure of water vapour

in the surrounding atmosphere. All the materials are sorbents to a lesser or greater extent. However, the term adsorbent refers to materials having large capacity for moisture as compared to their volume and weight. Such materials are classified into two general classification:

(a)Absorbent-

A sorbent which changes physically, chemically,or both during the sorption process is termed as an absorbent. Calcium Chloride is an example of a solid absorbent.

(b)Adsorbent-

A sorbent which does not change physically or chemically during the sorption process is termed as an adsorbent. At no time is there a phase change or solution of a adsorbent. Certain solid materials such as activated alumina,silica gel, activated bauxites and activated charcoal have this property. The action of adsorbents is, however,selective.

In order to be satisfactory for commercial dehumidification purposes,an adsorbent should have the following properties:

(a)It should have high adsorptive capacity.

(b)It should be chemically stable, resisting contamination from impurities.

(c) It should have physical ruggedness, to resist breakdown from handling and use, and high density to reduce bulk of handling.

(d)It should have capacity for regeneration at temperatures generally available.

(e)It should be thermally stable at regeneration temperature.

(f)it's cost should be reasonable.

2.2.2 SOLID ADSORBTION SYSTEMS

Solid adsorbent(desiccant) has the property of adsorbing moisture from an air water vapour mixture. Amount of air adsorbed is very small compared to the amount of water vapour adsorbed, and hence, dehumidification takes place. Adsorption occurs at the surface of the adsorbent *i.e.* the gas and the solid interface. Materials which are used commercially as solid adsorbent have a porous structure of submicroscopic dimensions with pore radii of few angstroms.

When an active adsorbent is brought in contact with a gas of high humidity, there is a tendency for vapour pressure of water in the adsorbent to reach equilibrium with the partial pressure of water in the surrounding gas, with the result that water is extracted from the gas and gas (air) is dehumidified. Adsorbents are said to be saturated for a given set of conditions when equilibrium is attained *i.e* the vapour pressure of water vapour in adsorbent and gas/air gets equalized..

Rate of water extraction is extremely rapid when the difference in the vapour pressures of water in the gas and water in the adsorbent is large. As the difference becomes small, rate of sorption decreases and hours may be required to reach equilibrium. Process of sorption by adsorbents is reversible. If the vapour pressure of adsorbed water becomes greater than the partial pressure of the vapour in the surrounding gas, water will be released by the adsorbent. This is called *reactivation* or *regeneration* . Reactivation temperature of common desiccants are within the range of 367 K to 533 K. Since no physical or chemical

change occurs to the adsorbent , it is again ready to extract water from moist air after so called *regeneration* . It is this property of reversibility which makes adsorption an economical process. Most solids are able to operate for thousands of *adsorption -regeneration* cycles.

Dehumidification by an adsorbent such as silica-gel may be performed under static or dynamic operation. In the static method, there is a natural circulating of gas through the desiccant. The air immediately surrounding the adsorbent is initially dried and subsequently , through diffusion and convection, water vapour from objects and spaces pass into the desiccant where it is adsorbed. Since considerable time may be required for air and the desiccant to reach equilibrium ,this type of dehumidification is best suited for small containers.

On the other hand, dynamic dehumidification is operated with forced flow of the air through the desiccant bed . It requires a desiccant bed, a fan to force the humid air through the desiccant bed, and a heater or some other source of heat energy to reactivate the bed periodically . As the air passes through the bed, it surrenders a certain amount of its water vapour content . The rate of moisture pick- up and the humidity content of the effluent air are function of many variables.

The ratio of the amount of water adsorbed by the desiccant bed in the given time to the amount of water vapour in the incoming air entering the desiccant bed during that time is known as *adsorption efficiency* . A characteristic of adsorbents in dynamic use is that this adsorption efficiency remains constant and at a relatively high level from the beginning of the

adsorption cycle until some later point in the cycle when the efficiency begins to drop. This point is known as *break point* and the time from the beginning of adsorption is known as *break point time* . The break point is also marked by a sudden increase in the adsorbate concentration of the effluent fluid. Although additional drying can be achieved beyond the break point , good commercial practice demands that the gel be regenerated in the vicinity of this point. The break point is very sharply defined in some cases , and in others , it is vaguely defined. Generally, the break point time decreases with the decrease in the bed thickness , increase in the particle size , increased rate of fluid flow through the bed , and an increase in the moisture content of the inlet air. There is a critical minimum bed height below which the moisture content in the effluent air will rise rapidly from the first appearance of the effluent. In planning new processes, it is best to determine the breakthrough curve experimentally under conditions resembling , as much as possible, those expected in the process.

CHAPTER 3

EXPERIMENTAL SET_UP AND PROCEDURE

3.1 SYSTEM DESCRIPTION

A Set-up was fabricated to study the dynamic behavior of silica gel bed. It had a duct section for heating and humidifying the ambient air so as to simulate hot and humid conditions , as prevailing in the coastal areas. Heating was done by electric heaters and humidification by steam-injection . Section for heating and humidification was followed by a duct section,to ensure proper mixing of air and steam. The centrifugal blowers were used to circulate hot and humid air through rectangular duct and finally through the cylindrical bed of silica gel The inlet dry-bulb and wet-bulb temperatures were measured.

The condition of air after dehumidification or regeneration, (depending upon whether the bed was regenerated or saturated)was measured at regular intervals of time,viz. at the intervals of one minute.

3.2 EXPERIMENTAL SET-UP

The experimental set-up is shown in figure no. 3.1. It had the following main components:

(a) Blowers

(b) Heating and Humidification arrangement

(c) Duct for Mixing of air

(d) Dehumidification and Regeneration arrangement.

M_1, M_2-Copper Tubes For Connection to the Manometer

B_1, B_2-Dummy and Test Columns

W_1, W_2-Wire Mesh Support

D-Hinged Door
(1-Closed, 2-Open)

T_1-Thermocouple Measuring the Inlet Wet-Bulb Temperature

T_2- Thermocouple Measuring the Inlet Dry-Bulb Temperature

CT-Contact Thermometer

B_3-Glass Beaker Containing Water to Wet the Wick

D_3- End Section of the Duct

FL-Flexible Joint Between D_3 and D_2

D_2- Middle Section of the Duct

S-Perforated Copper Tube For Steam Injection

H_2-Heating Element of the Boiler

H_1-Finned Air Heaters

D_1-First Section of the Duct

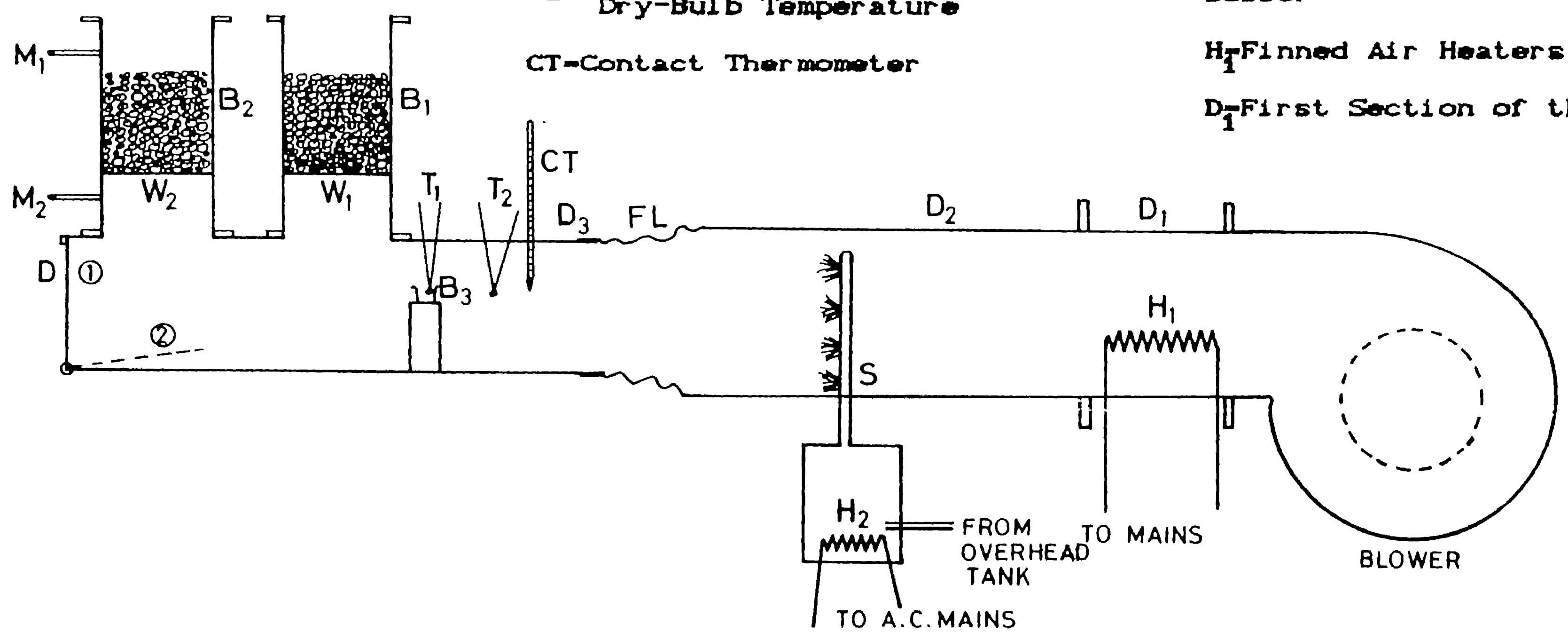


FIG. 3.1 SCHEMATIC DIAGRAM OF EXPERIMENTAL SET- UP

PLATE NO.1

PLATE NO.2

(e) Instrumentation for various measurements.

A detailed description of these components is given here. (Also see plate no. 1)

3.2.1 BLOWERS

Two blowers , connected in series were installed at the inlet section of the duct. This was done to increase the flow rate and to create pressure so as to overcome the flow resistance caused by the adsorbent bed. The specification of the blowers is as follows:

TYPE: LL

SIZE: 2 1/4

MAKE : Buffalo Air Conditioning Corporation

The blowers were driven by two single phase A.C. motors of 3/4 hp each running at a synchronous speed of 1420 R.P.M.

3.2.2 HEATING ARRANGEMENT

Heating was caused by a duct heater having six heating elements, connected in parallel. All the elements were of rectangular cross-section and had fins on them to facilitate heat transfer to the flowing air .

Two of the six elements were connected to the A.C. mains via a relay and an auto transformer (variac). This was done to control the rate of heat input and control the inlet air dry-bulb temperature-

---in dehumidification to keep the value equal to the desired simulated condition.

---in regeneration mode to keep it at a near constant value at 353 K..

The controlling relay took input power from the mains , the controlling signal from the contact thermometer, and supplied the output power to the variac, which supplied power to the two

heating elements. The contact thermometer was positioned such that its bulb was close to the thermocouple measuring the inlet dry-bulb temperature. Both the contact thermometer bulb and the thermocouple were positined near the entry to the bed of silica gel.

3.2.3 HUMIDIFICATION ARRANGEMENT

Humidification was necessary to create humid conditions as prevailing in coastal areas. Humidification was effected by steam injection . A steel cylinder served as a boiler drum.It contained two heating elements connected in parallel. One of the elements was connected to power supply via a variac so as to have control over the rate of steam injection. Steam was injected from a copper tube (dia 9mm) connected to the boiler and passing into the duct through the duct wall. The perforated copper tube was used for steam injection. To reduce energy loss from the boiler cylinder, glass wool pad and asbestos cloth was wrapped around the cylinder. A safe water level, as indicated by gauge glass , was maintained to prevent the heating elements from burning out. The water level was maintained by supplying tap water to the boiler.

3.2.4 DUCT

The duct consisted of three straight rectangular sections. First section was made of steel sheet . It's dimensions were 380mm X 300mm X 280mm . It contained the the duct heaters and was insulated thermally from the atmosphere by about 35mm thick glass wool pad. The blowers , supplied air through the duct heaters and finally to the test section mounted on the other end of the duct.

The second section of the duct was made of 20 gauge G.I. sheet with dimensions 1000mm X 380mm X 280mm. A tube passed through the side wall to inject steam. Care was taken to ensure

proper mixing of air with the injected steam to render a uniform temperature and humidity of the inlet air. This section was also thermally insulated by means of glass wool.

The end section , was connected to the second section by means of a rexine cloth flexible joint. It had a dimension of 900mm X 250mm X 200mm . The other end of this section had a sheet metal flap hinged to the edge of the duct section. This section had two holes of 150 mm diameter on the top horizontal surface for mounting the test column and the dummy column of perspex. The provisions were made for the dry-bulb thermocouple, the assembly for the inlet wet-bulb temperature and the contact thermometer. This section also was insulated using thermocole sheets.

3.2.5 DEHUMIDIFYING AND REGENERATION ARRANGEMENT

For dehumidification of air at simulated conditions and regeneration of saturated silica gel bed , two small cylinders of perspex (dia 150 mm, wall thickness 3 mm), having flanges at their ends were used. They contained silica gel of particle size 6.25mm to 10.0mm. Silica gel used was of self-indicating type , i.e.it turned pink when saturated and blue when regenerated.(see plate no.3) The two columns were identical in construction and geometry.In both the columns (at a height of about 200 mm from the base) two circular disks (of diameter approximately equal to the inside diameter of the columns) of perspex were fixed to act as flaps to control the volume flow rate of air through the silica gel bed. In the fully closed position the flaps rested over two semi circular rings fixed onto the inner walls of columns .The semi-circular rings acted as valve seats for the flaps These flaps could be rotated about a horizontal axis by means of a lever connected to it.

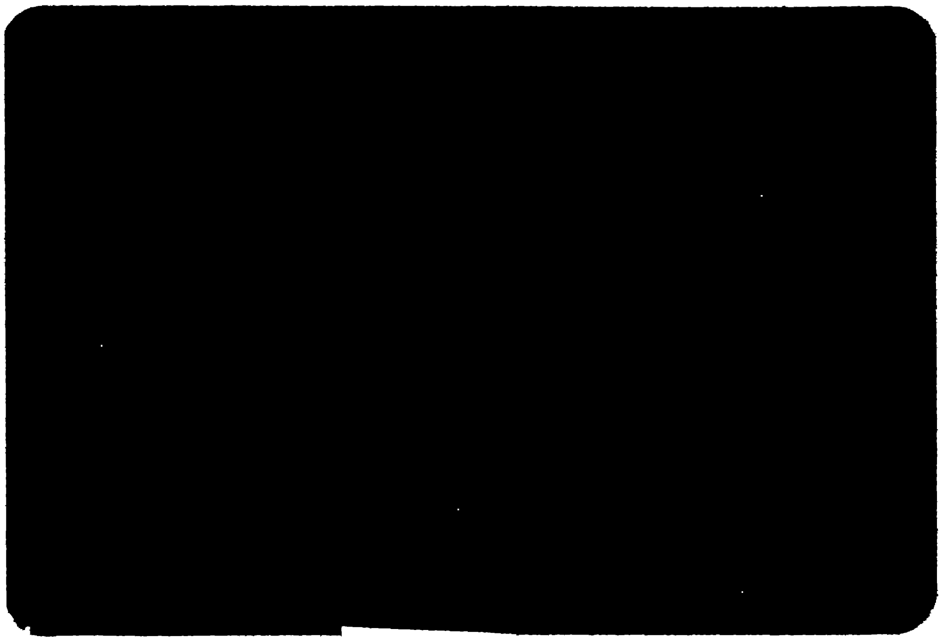


PLATE NO.3

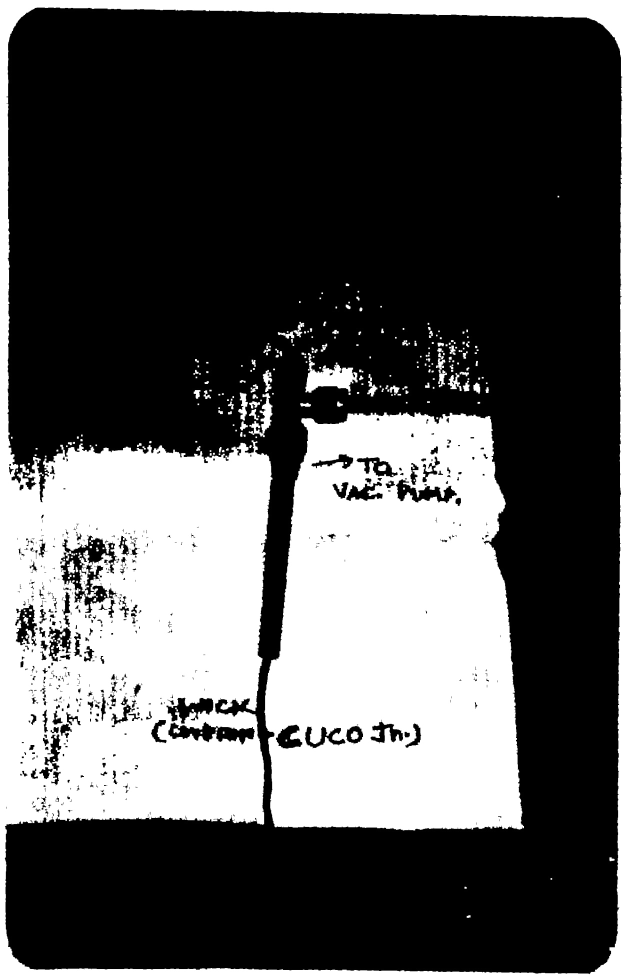


PLATE NO. 4

Only one of the columns acted as a test bed , while the other one acted as a dummy bed. When air at a desired condition was required to be passed through the test bed,in dehumidification mode, the flap of the test bed was closed and the flap of the dummy bed was kept open. When the inlet air reached a steady state and corresponded to the hot and humid conditions, the flap of test bed was opened and flap of the dummy bed was closed.

Similarly , in the regeneration mode , flap of the dummy bed was kept open and that of the test bed was kept closed, while the heaters were switched on and the inlet air reached a steady state temperature equal to the desired regeneration temperature. After steady state was reached , flap of the test bed was opened and the flap of the dummy bed was closed.

In each of the columns ,at equal height from the base of the columns, four small pieces of perspex were fixed on the inner walls of the columns by Chloroform. A circular piece of wire mesh , riveted to a ring of G.I. sheet, was kept over these perspex pieces in order to form a support base for the silica gel bed. Two holes (one above the adsorbent bed and one below the adsorbent bed) were drilled, and through these holes, two copper tubes were passed, to provide connections to the two limbs of an inclined tube manometer.(See plate no.2)

After fabrication of the the test column, the same was subjected to a test leaks. It was necessary in the light of strong affinity of the adsorbent for the atmospheric moisture. Both the ends of the test columns were sealed by clamping two greased perspex plates, pressurized air was fed into the column through one of the two copper tubes fitted for pressure drop measurement. Soap solution was applied at all suspected points for

leak , and detected leaks were closed by a paste of perspex and chloroform.

3.3 INSTRUMENTS AND MEASUREMENTS

3.3.1 TEMPERATURE AND HUMIDITY MEASUREMENT

Temperature and specific humidity of air, entering and leaving the adsorbent bed were measured. For the measurement of dry-bulb temperatures of inlet and exit air,Copper-Constantan (CuCO) thermocouples made from 30 gauge wires were used. The thickness of wire was selected on the basis of two conflicting requirements: thinner wires led to a smaller time constant of the junction,and thus made it more suitable for unsteady state measurements , but,very thin wires always had the tendency of breaking of the junction during handling. Although thicker wires ensured the strength of the junction ,it had a large time constant. The thermocouple output was fed to THERM 3280-6 TEMPERATURE RECORDER (Measuring Range with CuCO Junction: 73 K to 873 K ; Resolution: 0.1 K). The recorder had in built compensation for variation in the atmospheric temperatures and directly displayed the junction temperature on the LCD display. The junction measuring inlet air dry bulb temperature was passed through the duct wall and sealed to the wall by M-Seal The junction measuring exit dry bulb temperature was tied to a tube and kept at the mouth of the perspex test bed.

Humidity measurements at the inlet and exit conditions were done by measuring the corresponding dry-bulb ant wet-bulb temperatures and calculation (using a PASCAL program) based on following equations [19] were carried out for specific humidity values.

$$P_{sat} = 221.287/\exp [\{ 7.21379 + (1.152 \times 10^{-9} - 4.787 \times 10^{-9} T_{db})(T_{db} - 483.15)^2 \} (647.31/T_{db} - 1)] \quad (1)$$

$$P_v = P_{vb} - 6.66 \times 10^{-4} P_a (T_{db} - T_{wb}) \quad (2)$$

$$w = 0.622 P_v / (P_{atm} - P_v) \quad (3)$$

(All temperatures in Kelvin and pressures in bar)

Wet-bulb temperatures were measured using 30 gauge CUCO thermocouple. The junctions were cleaned and a clean Egyptian cotton cloth piece was snugly wrapped around the junctions. To make sure that the Lewis Number was close to unity, and thus, the wet bulb temperature nearly close to the thermodynamic wet bulb temperature, an air velocity of the order of 4.5 m/s (270 m/min) was desired to be created across the wet junction

This was achieved by encasing the wet junction inside a 6 mm copper tube . The copper tube being connected to a T joint of which , one end was led to a vacuum pump. Through the other end of the T joint thermocouple leads were taken out and the end was sealed M- Seal (See plate no.4). Two such assemblies were prepared , one each for measuring the inlet and the outlet wet bulb temperatures. Two tube connections , one each from the two T joint assemblies , were connected to a vacuum pump via two regulating valves and a T joint. Depending on whether the inlet or the outlet wet bulb temperature was to be measured , the corresponding regulating valve was opened, the other one being kept closed. The thermocouple wires were connected to the THERM 3280-6 temperature recorder. The wicks were constantly kept moistened by dipping the ends of wicks in two small glass beakers which were periodically filled . To avoid errors creeping in due to heating of the wires wetting the junctions ,and to prevent the direct heating of the wet junctions from the surrounding hot air,

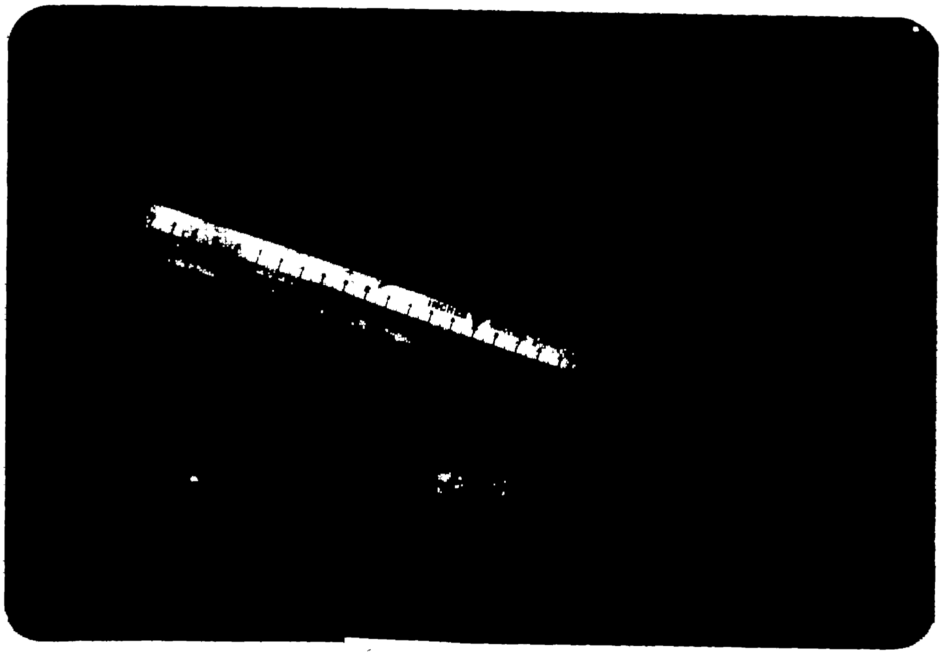


PLATE NO.5

the copper tube encasing the wet junctions, and the glass beakers were insulated.

By pressing a button at the front panel of the THERM 3280-6 recorder, one could read the instantaneous temperature of any of the four junctions. Extensions from the thermocouple wires to the temperature recorder were provided by means of insulated copper wires. It was ensured that the two copper wire -- thermocouple wire junctions, corresponding to each thermocouple, were exposed to same temperature and velocity conditions.

3.3.2 FLOW RATE MEASUREMENT

Flow rate of air through the test bed was measured using a small vane anemometer probe (no.642a-m/3-2 ; Range: 0.60m/s to 40.00 m/s ; Resolution: 0.01 m/s) connected to THERM 2285-2 velocity and temperature recorder. The instrument had an in_ built integration circuit so that one could directly read the average flow velocity across the cross-section of the bed.

3.3.3 PRESSURE DROP MEASUREMENT

Pressure drop across the test bed was measured by an inclined manometer (inclined at an angle of 30° to the horizontal. It contained red oil fluid and having calibration on inches of water. (See plate no. 5) Pressure drops were measured for different bed thicknesses .

3.4 EXPERIMENTAL PROCEDURE

DEHUMIDIFICATION MODE

In the beginning , silica gel was filled up to desired height in test column as well as in the dummy column. Both the blowers were switched on and the flap at the bottom of dummy adsorbent

column was opened, the flap at the bottom of the test column being kept tightly closed. Both beakers for wetting the wicks were filled with distilled water. The dry-bulb temperature of inlet air was set at desired value by adjusting the contact thermometer, switching on the power supply to the heating element which was connected to the variac, and adjusting the output voltage of the variac. The approximate dry-bulb temperature was set by contact thermometer ,and, the actual value was obtained by adjusting the dial of variac and fine setting of contact thermometer. Thus the desired inlet dry-bulb temperature was achieved.

Once the desired dry bulb temperature was attained, the boiler, having adequate amount of water,was switched on. Regulating valve connecting the vacuum pump to the inlet wet-bulb assembly,was opened .The output of variac supplying power to the heating element in the boiler was controlled such that the desired value of inlet wet-bulb temperature was achieved.

After attainment of steady values of dry-bulb and wet-bulb temperatures, the simulated air was passed through the test column by opening the flap at its bottom , and the one at the bottom of the dummy column was kept tightly closed. Dry-bulb and wet-bulb temperatures of exit air was measured at regular intervals of one minute each.

REGENERATION MODE

An identical procedure as above was adopted for the regeneration mode as well. The main difference lay in the fact that this time four remaining heating elements of the duct heaters were also switched on , all of them connected directly to the A.C. mains. After regeneration , the test column was left for cooling down to the ambient temperature. This was followed by another

cycle of dehumidification and regeneration. Such cycles were repeated for three different values of bed thicknesses and three different values of inlet wet-bulb temperatures, value of dry bulb temperature and the flow velocity being kept constant.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS OF EXPERIMENTS IN DEHUMIDIFICATION MODE

Dehumidification of simulated air by silica gel bed was studied for varying conditions. *Firstly*, wet-bulb temperature was varied as 301 K, 303 K, 307 K. *Secondly*, the bed thickness was kept as 101.6 mm (4inches), 177.8mm(7inches), and 254mm (10 inches). Irrespective of the values of inlet wet-bulb temperature and the value of bed thickness the inlet dry-bulb temperature was maintained at a value of 311 K and air flow velocity at 0.9 m/s.

4.1.1 DEHUMIDIFICATION WITH BEDS WITHOUT ANY COOLING

Outlet dry and wet-bulb temperatures were measured at an interval of one minute each. Outlet specific humidity was calculated and the same is plotted against time in Figs. 4.1 to 4.4 for different bed thicknesses and varying inlet air conditions.

Figure 4.1 shows the time-wise variation of outlet specific humidity for three bed thicknesses and for inlet air Dry-bulb temperature of 311 K and wet-bulb temperature of 301 K. For the bed thickness of 254 mm the outlet specific humidity varies smoothly till 10 minutes from the beginning of dehumidification, then it increases suddenly from 0.016Kg/ Kg of dry air to a value of 0.018 Kg/Kg of dry air. Thereafter it smoothly and slowly increases up to the saturation value of 0.021 Kg/Kg of dry air. After 36 minutes , no change was observed in the outlet air conditions. This, accompanied by a colour change of silica gel bed

to pink indicated the saturation of the 254 mm bed at time equal to 36 minutes. The point of sudden jump in outlet specific humidity *i.e. the break point* is at time equal to 10 minutes. Similarly for the 177.8 mm thick bed, we find the *break point at* time equal to 7 minutes and the saturation time of the bed equal to 26 minutes. However, for the 101.6 mm thick bed we do not see similar distinct break point. In this case , the outlet specific humidity increases at a smooth rate till the saturation of the bed at time equal to 16 minutes.

Figure 4.2 shows similar variation of outlet specific humidity with time for different bed thicknesses and inlet air conditions of dry-bulb temperature equal to 311 K and wet-bulb temperature equal to 303 K. The curve for the 254 mm thick bed shows a near constant (slowly increasing) specific humidity up to 8 minutes from the beginning of dehumidification where the specific humidity value is 0.0164 Kg/Kg of dry air. After the sudden jump at braking time *i.e.* 8 minutes it increases smoothly and slowly till the saturation of the bed at time equal to 33 minutes . Similarly, the 177.8 mm thick bed shows a break point time of 6 minutes and the saturation time of 23 minutes. However, for the 101.6 mm thick bed again, we do not see any break point. The specific humidity increases, monotonously , from the beginning of dehumidification to saturation at time equal to 16 minutes.

Figure 4.3 shows the variation of outlet specific humidity with time for the three different bed thicknesses and the inlet air with dry-bulb temperature of 311 K and wet-bulb temperature of 305 K . For 254 mm thick bed, the specific humidity remains at a near constant value (actually it increases very slowly) from the

beginning of dehumidification to the break point time of 6 minutes. After the sudden jump in specific humidity at break point, it increases slowly up to the value of 0.0355 Kg/Kg of dry air at saturation time of 27 minutes. For the 177.8 mm thick bed, the values of break point time and saturation time values are 5 minutes and 21 minutes respectively. However, for the 101.6 mm thick bed, the outlet specific humidity does not remain at a near constant value even just after the beginning of dehumidification and goes on increasing at faster rate compared to the thicker beds , till its saturation at a time of 10 minutes.

Figures 4.5 to 4.7 show the variation of dry-bulb temperature of effluent air ,in dehumidification mode, with time All the curves show the same nature *i.e.*,a very rapid increase in the effluent dry-bulb temperature in the vicinity of the beginning of dehumidification , reaching a peak value (which decreases with decrease in the bed thickness for a given inlet air conditions.)followed by slow decrease till the bed reaches saturation. In all the cases the final value of effluent dry-bulb temperature is higher than the dry-bulb temperature of inlet air.

4.1.2 DEHUMIDIFICATION WITH COOLED BED

Few vertical rows of copper tubes were immersed in a 177.8 mm thick bed of silica gel bed. Tap water at a temperature of 307K (34^{o}C)and at a flow rate of 87 ml/s was passed through these copper tubes while the bed was being used to dehumidify air at respective dry and wet-bulb temperatures of 311 K and wet-bulb temperature of 307 K . With the immersion of copper tubes the amount of silica gel in the bed was less compared to a normal 177.8 mm thick bed. To take care of this effect, dehumidification

was also studied with the copper tubes immersed , but, without circulating any cooling water. Variation of outlet specific humidity *vs.* time , for these two cases is shown in Fig.4.4. In the cooled bed condition, the outlet specific humidity increases very slowly from the beginning of dehumidification up to the break point *i.e.* 6 minutes from the beginning of dehumidification, takes a jump at the break point and then slowly increases till the bed reaches saturation 22 minutes from beginning of dehumidification. Compared to this , in the corresponding uncooled bed, we see a similar nature of curve , but a lower value of break point time-5 minutes and saturation time of 20 minutes. Besides, the value of outlet specific humidity at the break point is lower in the case of cooled bed (0.0265 Kg/Kg of dry air) as compared to the corresponding value of uncooled bed(0.0274 Kg/ Kg of dry air).Fig. 4.8 shows the variation of effluent dry-bulb temperature for these two beds. The value of peak dry-bulb temperature in the case of uncooled bed is higher (331.6 K) as compared to the cooled bed (326 K). In addition of this the rate of temperature is higher in the case of uncooled bed.

4.2 RESULTS OF EXPERIMENTS IN REGENERATION MODE

The simulated hot and humid air was further heated , by means of finned duct heaters, and a dry-bulb temperature of 353 K to 357 K was maintained. This temperature range was selected such that even flat plate solar collector may be used to regenerate silica gel bed. Similar to the dehumidification mode, the effluent dry and wet bulb temperatures were was measured. The steady condition of regeneration under given condition was indicated by effluent dry-bulb temperature reaching a steady value. the same

was plotted against time for varying bed thicknesses and varying air conditions in Figs.4.9 to Fig. 4.12 All the curves show a similar nature *i.e.* a rapid rate of increase of dry-bulb temperature followed by a decreasing rate of temperature rise till the attainment of steady state by the bed. Figs. 4.9 to Fig. 4.11 show that for given condition of regenerating air, the time of regeneration increases with increase in the bed thickness. Figure 4.12 exhibits aninteresting result. The rate of temperature-rise is faster in the case of insulated column as compared to rate of temperature-rise in the case of uninsulated column. The regeneration time is less in the case of insulated column (15 minutes) as compared the corresponding value of uninsulated column (22 minutes).

4.3 PRESSURE DROP MEASUREMENT.

Pressure drop across the different bed thicknesses , for varying conditions, was measured in the dehumidification mode after the beds reached saturation state. It was observed that the pressure drop changes only with the change in the bed thickness. The curve fitting of the observed values gives the following linear relationship between the pressure drop (in mm of water) and the bed thickness (mm of bed thickness) (See Fig. 4.13)

$$\Delta P = 0.21332X - 3.97833$$

(X is the column thickness in mm)

4.4 CURVE FITTING FOR EMPIRICAL RELATIONS OF IMPORTANT PARAMETERS

Based on the results of experiment conducted (SUMMARY OF RESULTS IS TABULATED IN TABLE 4.1) and results obtained, mathematical correlations were obtained for *saturation time, regeneration time and peak dry-bulb temperature*. (of effluent air

in the dehumidification mode) The method adopted is given here.

Let us first consider the regeneration time for obtaining a correlation for the same in terms of relevant parameters. The results show that the regeneration time of a silica gel bed varies both due to a variation in the relative humidityand bed thickness.

First we consider the variation of regeneration time with relative-humidity. Entry in 2nd, 3rd and 4th rOw of 5th column of the table give the values of regeneration time for three beds of, thickneses 101.6mm, 177.8mmand 254 mm with simulated air having a relative humidity of 46.8 %(Dry-Bulb Temperature of 311 K and Wet -Bulb Temperature of 301 K)The best fit curve for this variation is given as foolows: (GRAPHER software was used to get the best -fit curves.)

$t_{reg.} = 0.104987X + 5.3333$ (Eq.4.1)

$T_{reg.}$ is the regeneration time in minutes

X is the bed thicknes in mm.

Similarly the best fit curve for simulated air with relative humidity equal to 55.9 % (DBT=311K , WBT= 303K) is given as follows:

$t_{reg.} = 0.103018X + 5.2333$ (Eq. 4.2)

For the case of relative-humidity of 76.2 % (DBT= 311K , WBT= 307K), the best-fit curve is given as follows:

$t_{reg.} = 0.104987X + 5$ (Eq. 4.3)

Now, we see that all the best-fit curves are straight lines with differing slopes and intercepts. We treat the slopes and intercepts as functions of relative humidity and obtain -fit curves for this variation as follows:

$$Slopoe = 0.0000304R + 0.101948 \qquad (\text{Eq. } 4.4)$$

R is relative humidity in terms of percentage.

and,

$$Intercept = 0.0087997R + 5.16237 \qquad (\text{Eq. } 4.5)$$

On the basis of Eq. 4.1 to Eq. 4.5, we can write the corelation for the regeneration time , in terms of relative-humidity and bed thickness as:

$$t_{reg.} = 0.0000304RX + 0.101948X - 0.0087997R + 5.16237 \qquad (\text{Eq. } 4.6)$$

Exactly on the same lines, the correlation for the bed saturation time and the peak dry-bulb temperature of effluent air(dehumidification mode) is given as below:

$$t_{sat.} = 1.49491X - 0.00046752RX - 0.11578R + 8.51583 \qquad (\text{Eq. } 4.7)$$

$$T_{peak} = 0.000005496RX + 0.04946X + 0.19004R + 36.4118 \qquad (\text{Eq. } 4.8)$$

X= bed thicknes in mm , R= Relative Humidity in percentage.

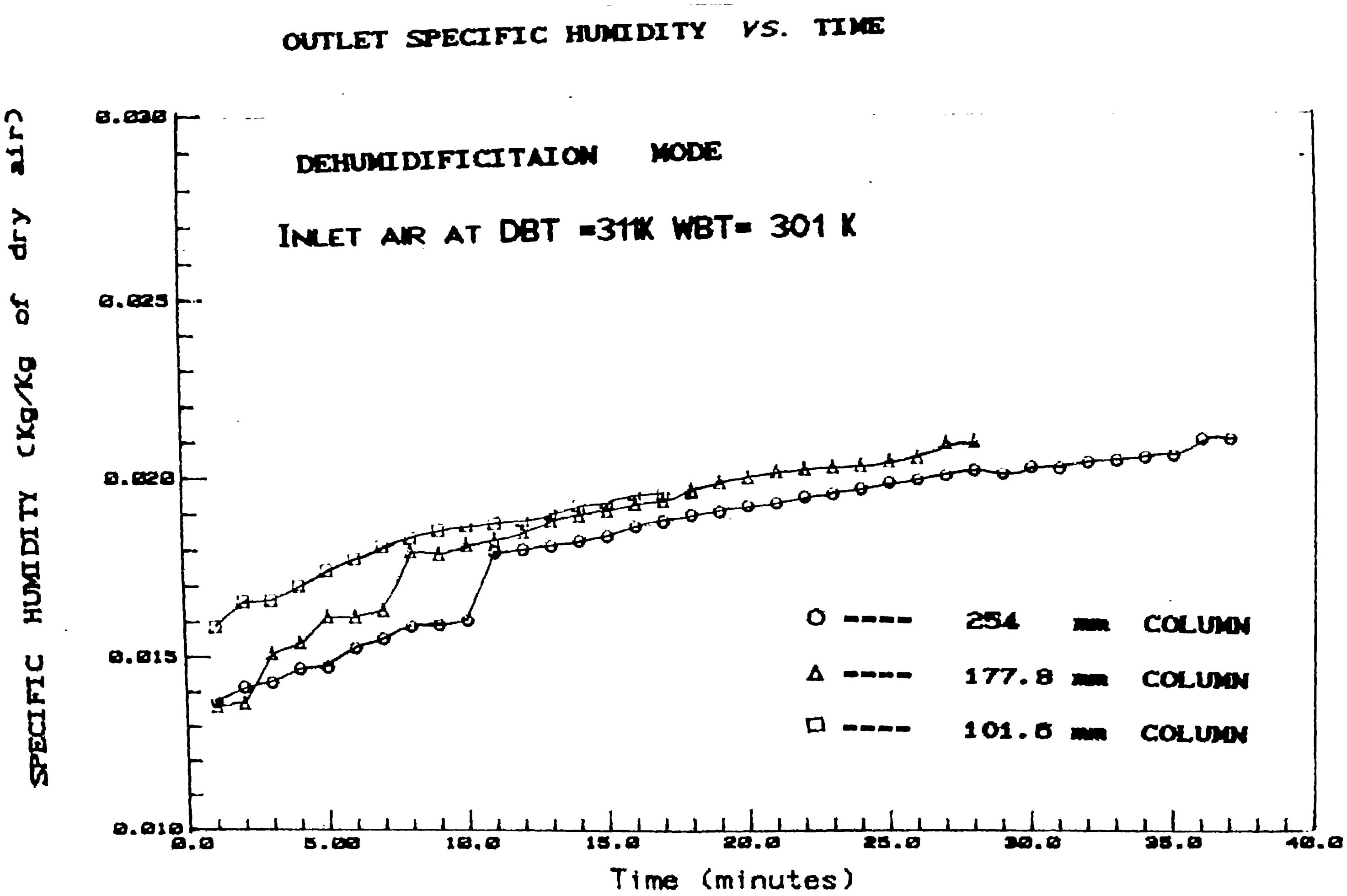

OUTLET SPECIFIC HUMIDITY VS. TIME
DEHUMIDIFICITAION MODE
INLET AIR AT DBT =311K WBT= 301 K
O ---- 254 mm COLUMN
Δ ---- 177.8 mm COLUMN
□ ---- 101.6 mm COLUMN
SPECIFIC HUMIDITY (Kg/Kg of dry air)
Time (minutes)
0.030
0.025
0.020
0.015
0.010
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0

FIG. 4.1

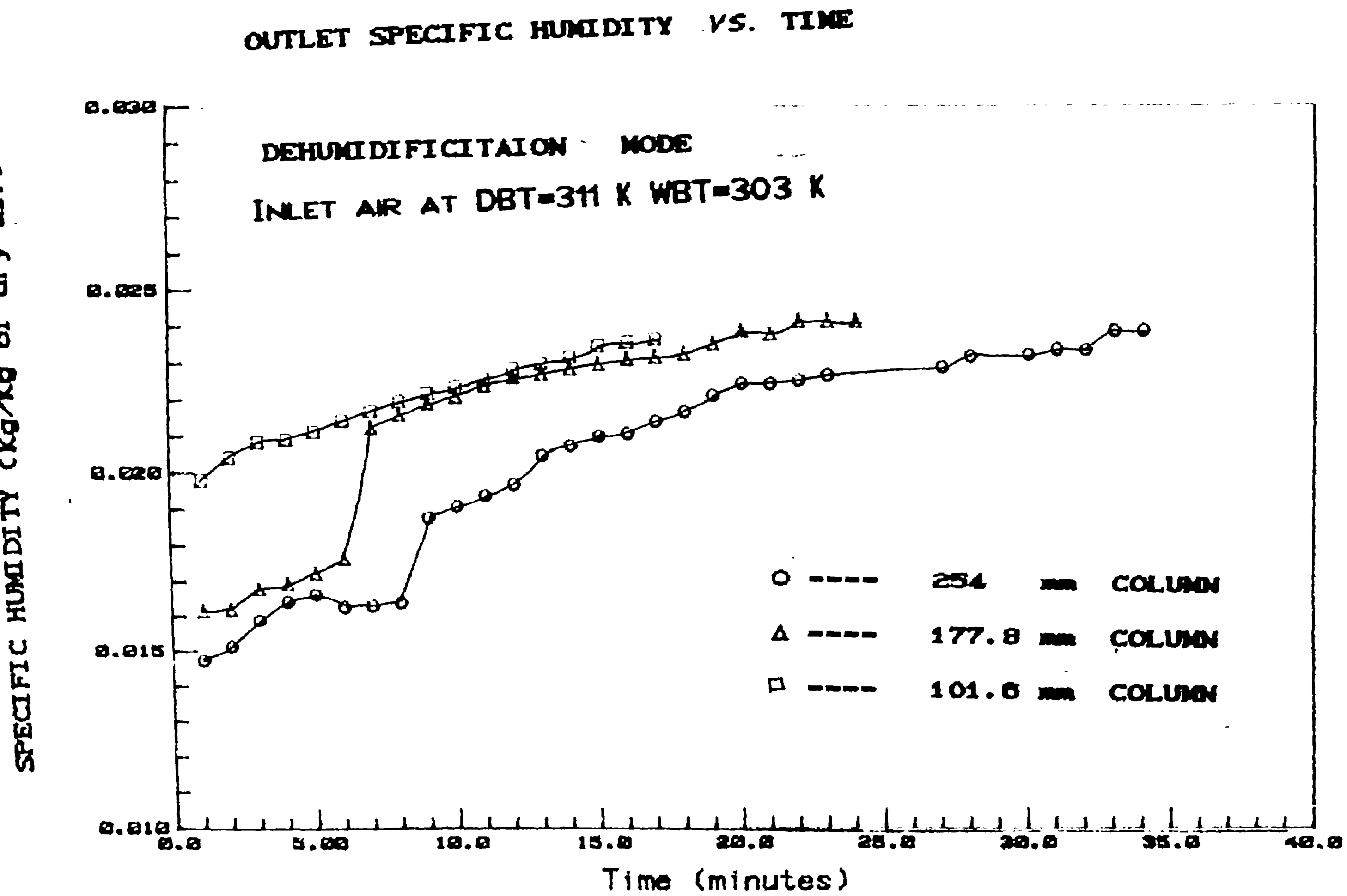
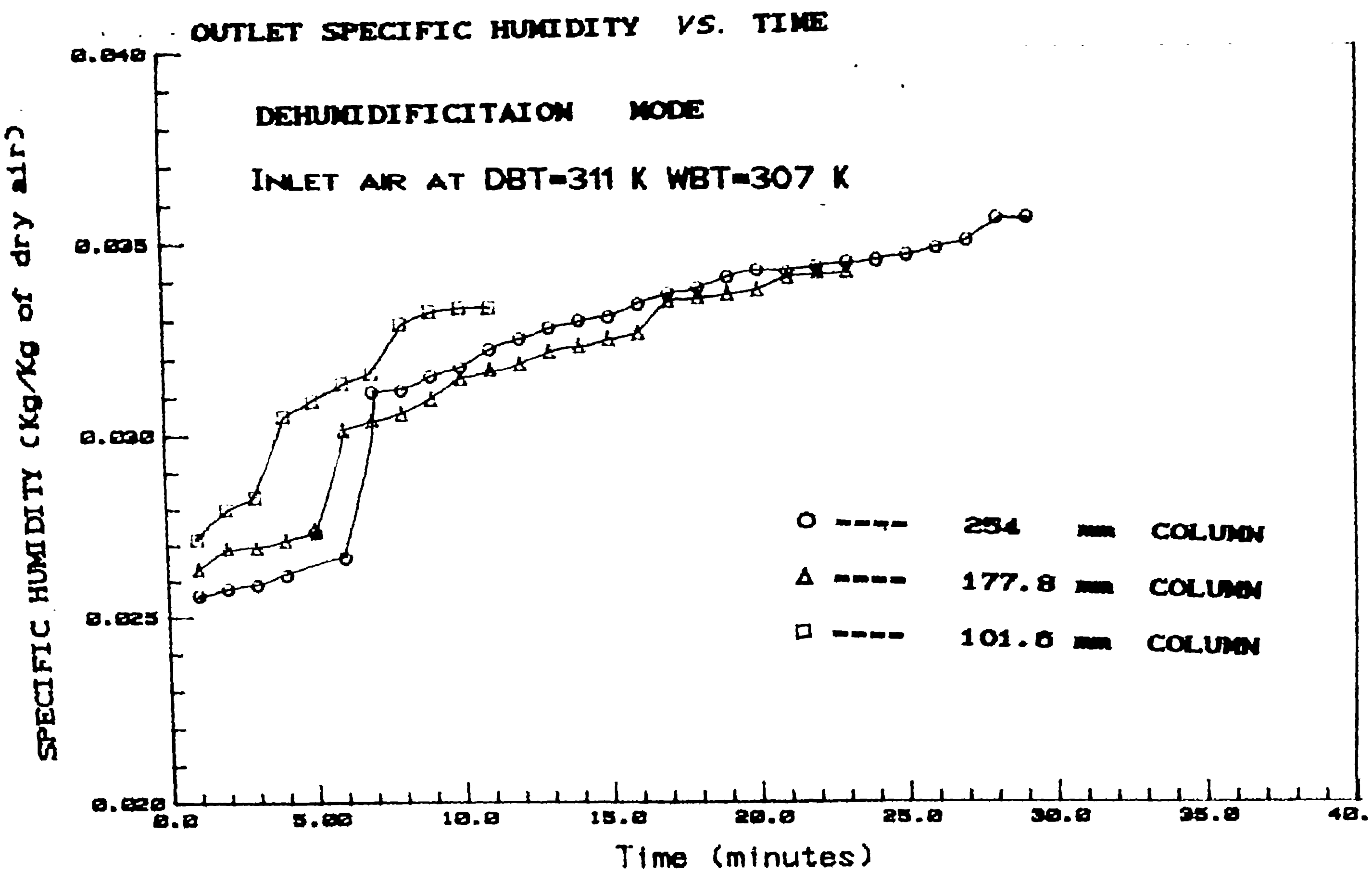

OUTLET SPECIFIC HUMIDITY VS. TIME
DEHUMIDIFICITAION MODE
INLET AIR AT DBT=311 K WBT=303 K
SPECIFIC HUMIDITY (Kg/Kg of dry air)
Time (minutes)
0.030
0.025
0.020
0.015
0.010
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
O ---- 254 mm COLUMN
Δ ---- 177.8 mm COLUMN
□ ---- 101.6 mm COLUMN

FIG.4.2



OUTLET SPECIFIC HUMIDITY VS. TIME
DEHUMIDIFICITAION MODE
INLET AIR AT DBT=311 K WBT=307 K
SPECIFIC HUMIDITY (Kg/Kg of dry air)
0.040
0.035
0.030
0.025
0.020
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Time (minutes)
254 mm COLUMN
177.8 mm COLUMN
101.6 mm COLUMN

FIG.4.3

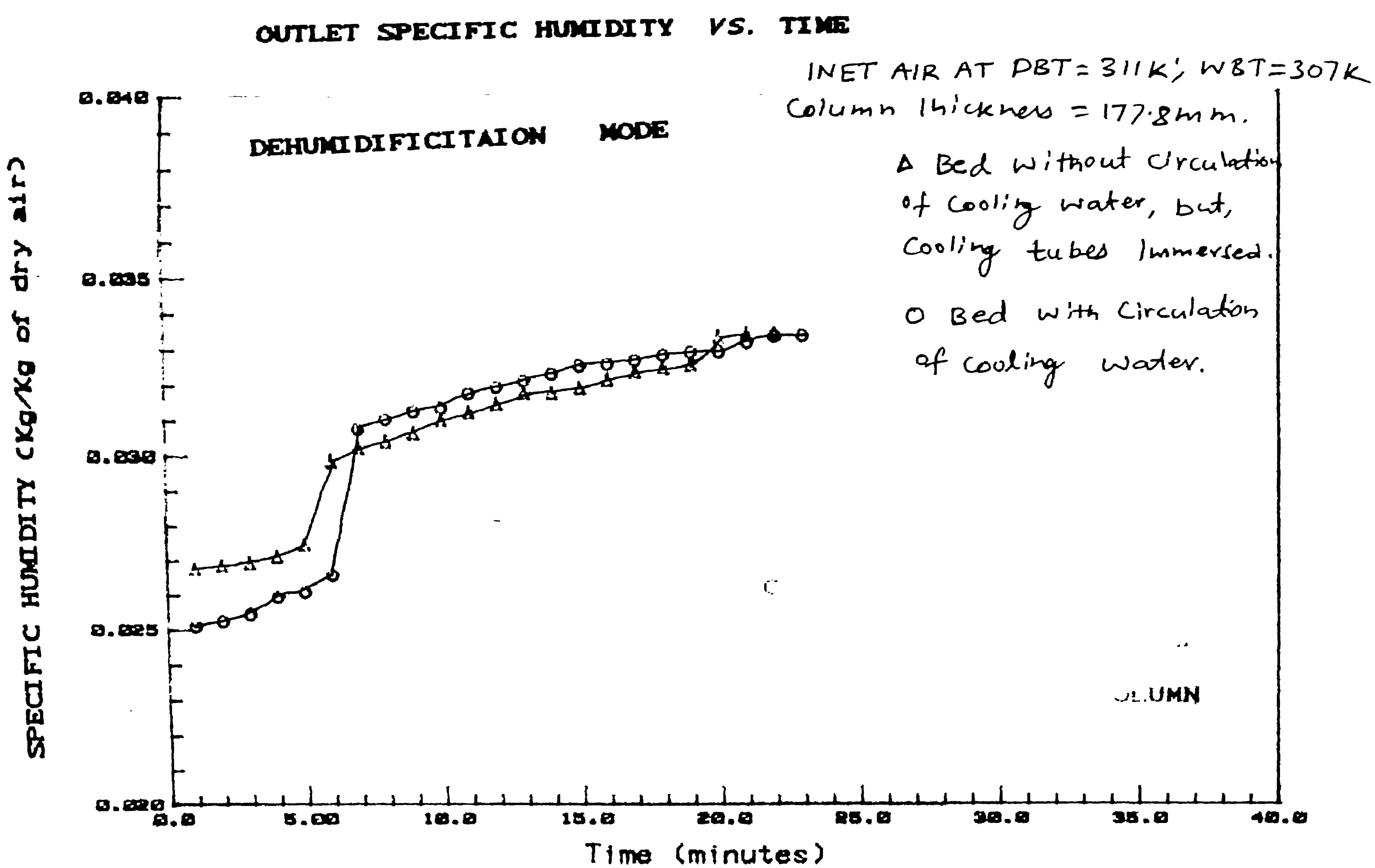


FIG.4.4

Graphstar

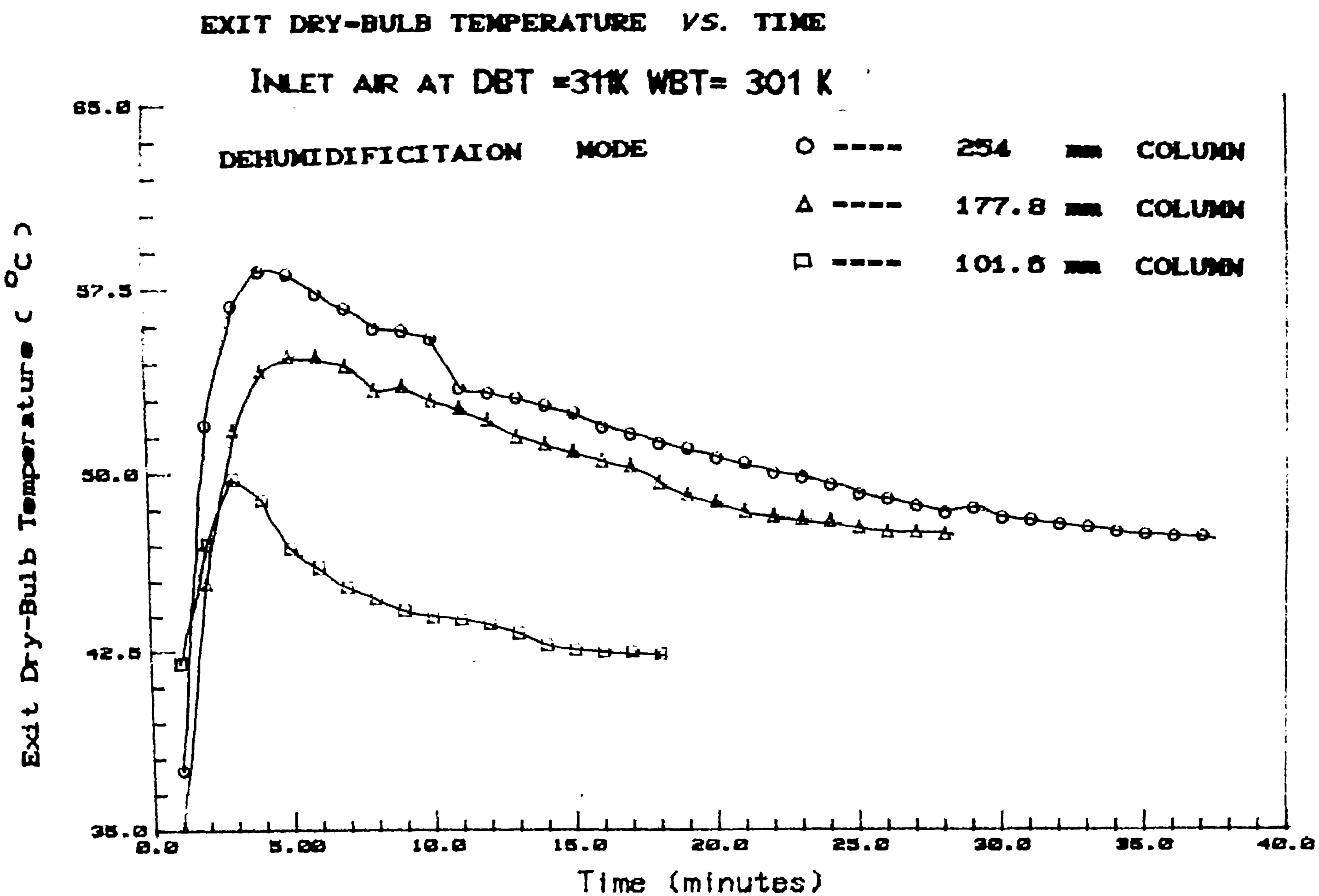
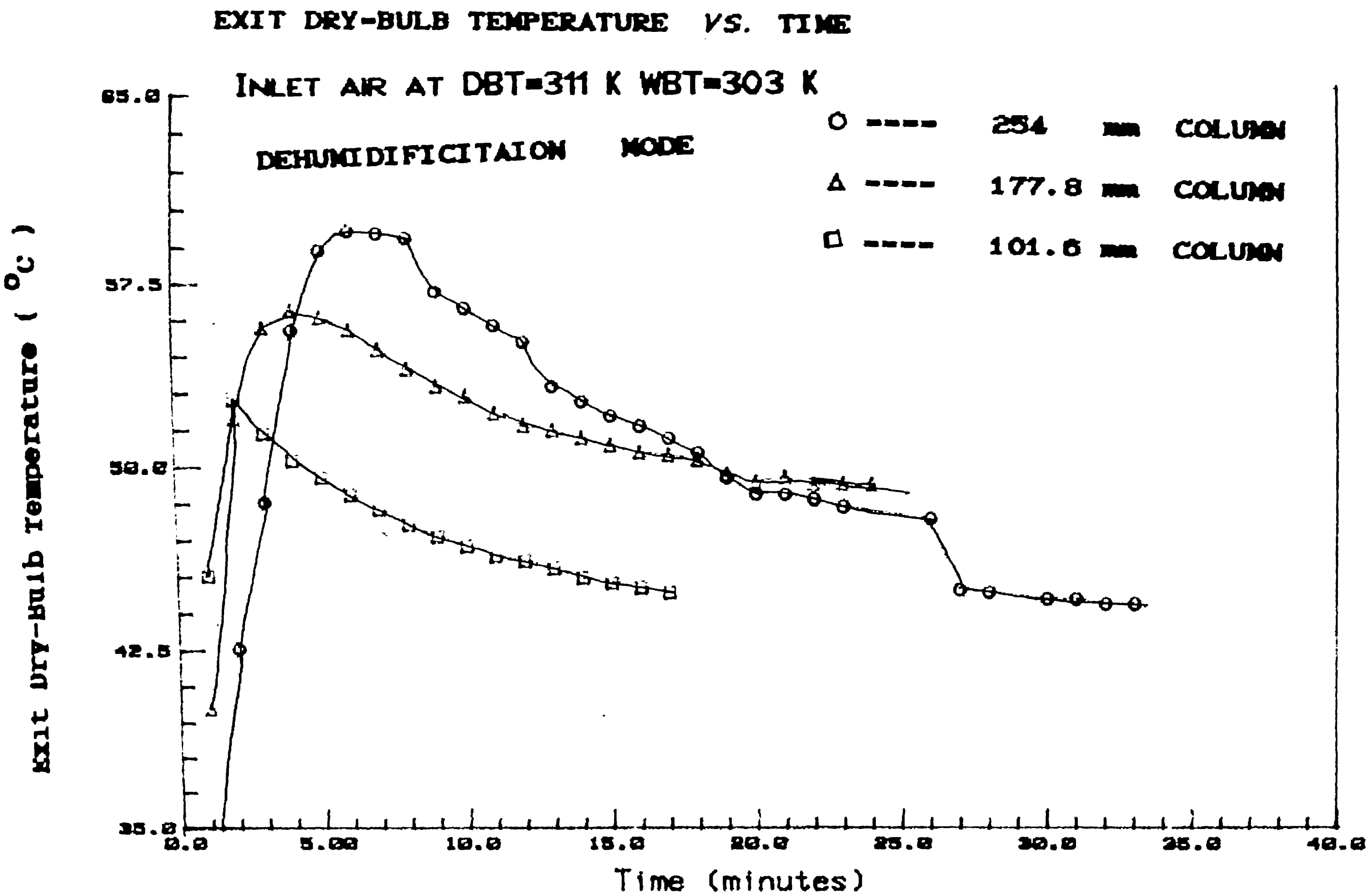

EXIT DRY-BULB TEMPERATURE VS. TIME
INLET AIR AT DBT =311K WBT= 301 K
DEHUMIDIFICITAION MODE
O ---- 254 mm COLUMN
Δ ---- 177.8 mm COLUMN
□ ---- 101.6 mm COLUMN
Exit Dry-Bulb Temperature (°C)
65.0
57.5
50.0
42.5
35.0
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Time (minutes)

FIG.4.5



EXIT DRY-BULB TEMPERATURE VS. TIME
INLET AIR AT DBT=311 K WBT=303 K
DEHUMIDIFICITAION MODE
O ---- 254 mm COLUMN
Δ ---- 177.8 mm COLUMN
□ ---- 101.6 mm COLUMN
65.0
57.5
50.0
42.5
35.0
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Time (minutes)
Exit Dry-Bulb Temperature (^{o}C)

FIG.4.6

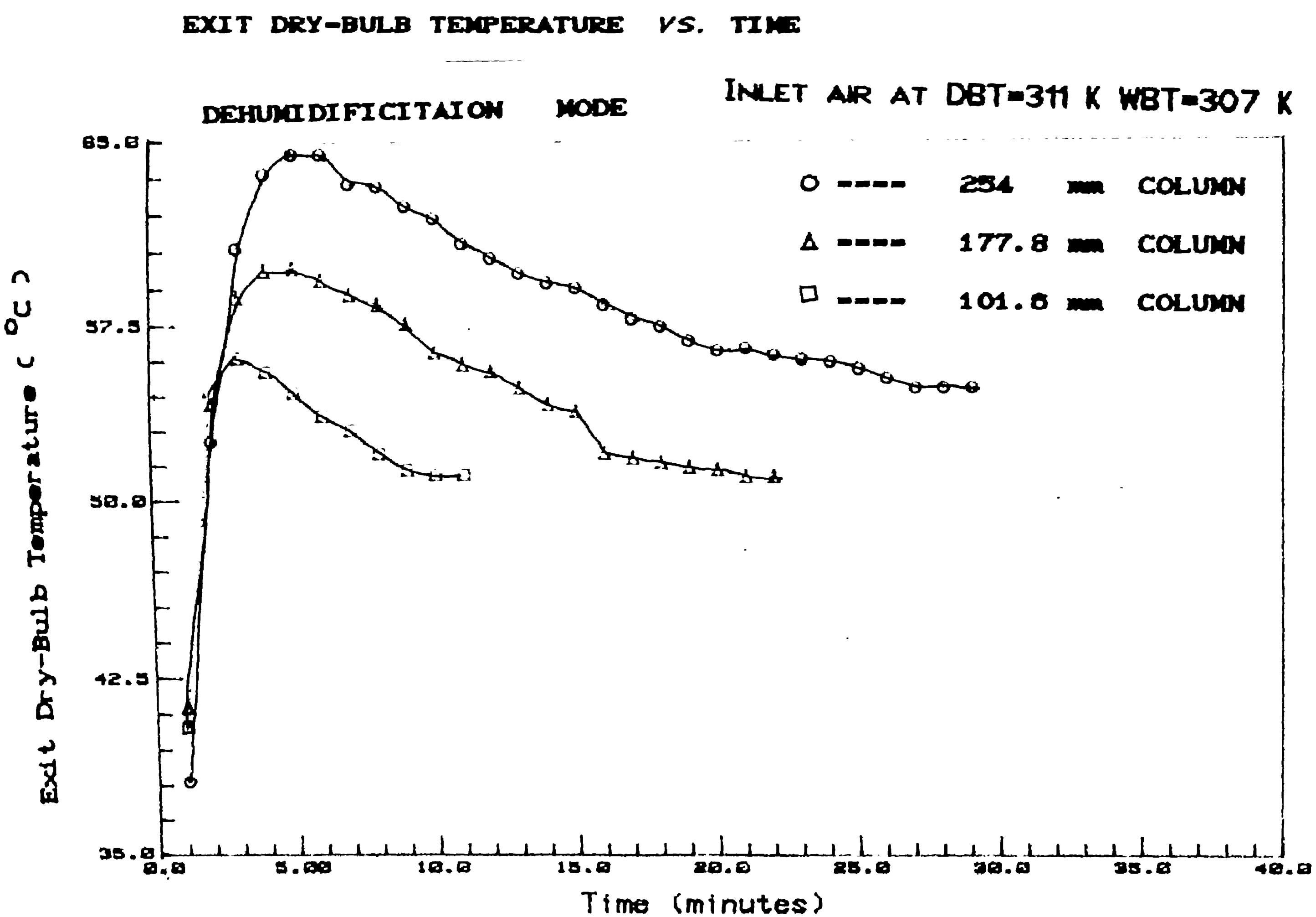

EXIT DRY-BULB TEMPERATURE VS. TIME
DEHUMIDIFICITAION MODE
INLET AIR AT DBT=311 K WBT=307 K
O ---- 254 mm COLUMN
Δ ---- 177.8 mm COLUMN
□ ---- 101.6 mm COLUMN
65.0
57.5
50.0
42.5
35.0
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Exit Dry-Bulb Temperature (°C)
Time (minutes)

FIG.4.7

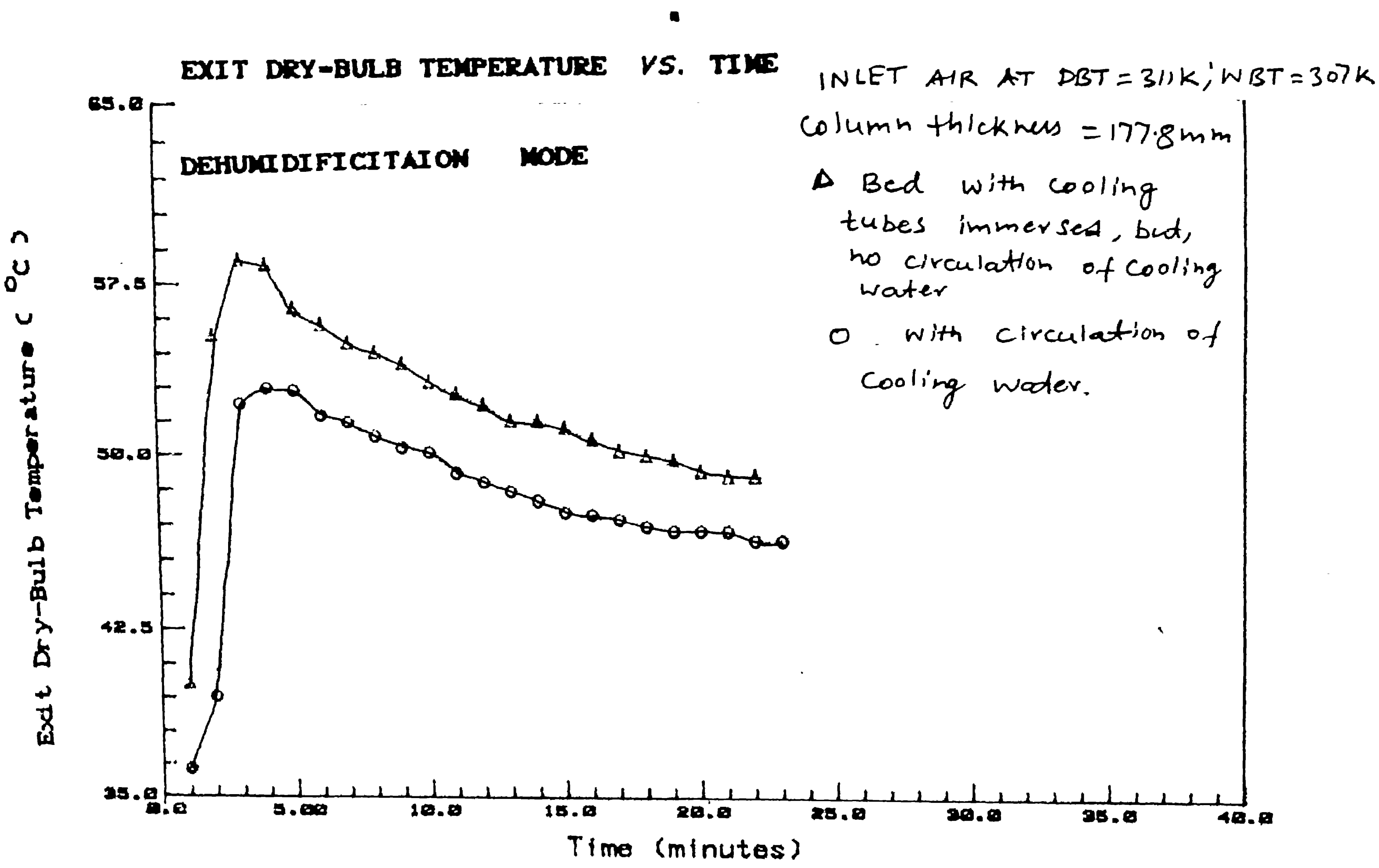

EXIT DRY-BULB TEMPERATURE VS. TIME
DEHUMIDIFICITAION MODE
INLET AIR AT DBT = 311K; WBT = 307K
Column thickness = 177.8mm
Δ Bed with cooling tubes immersed, bed, no circulation of cooling water
O with circulation of cooling water.
Exit Dry-Bulb Temperature (°C)
65.0
57.5
50.0
42.5
35.0
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Time (minutes)

FIG.4.8

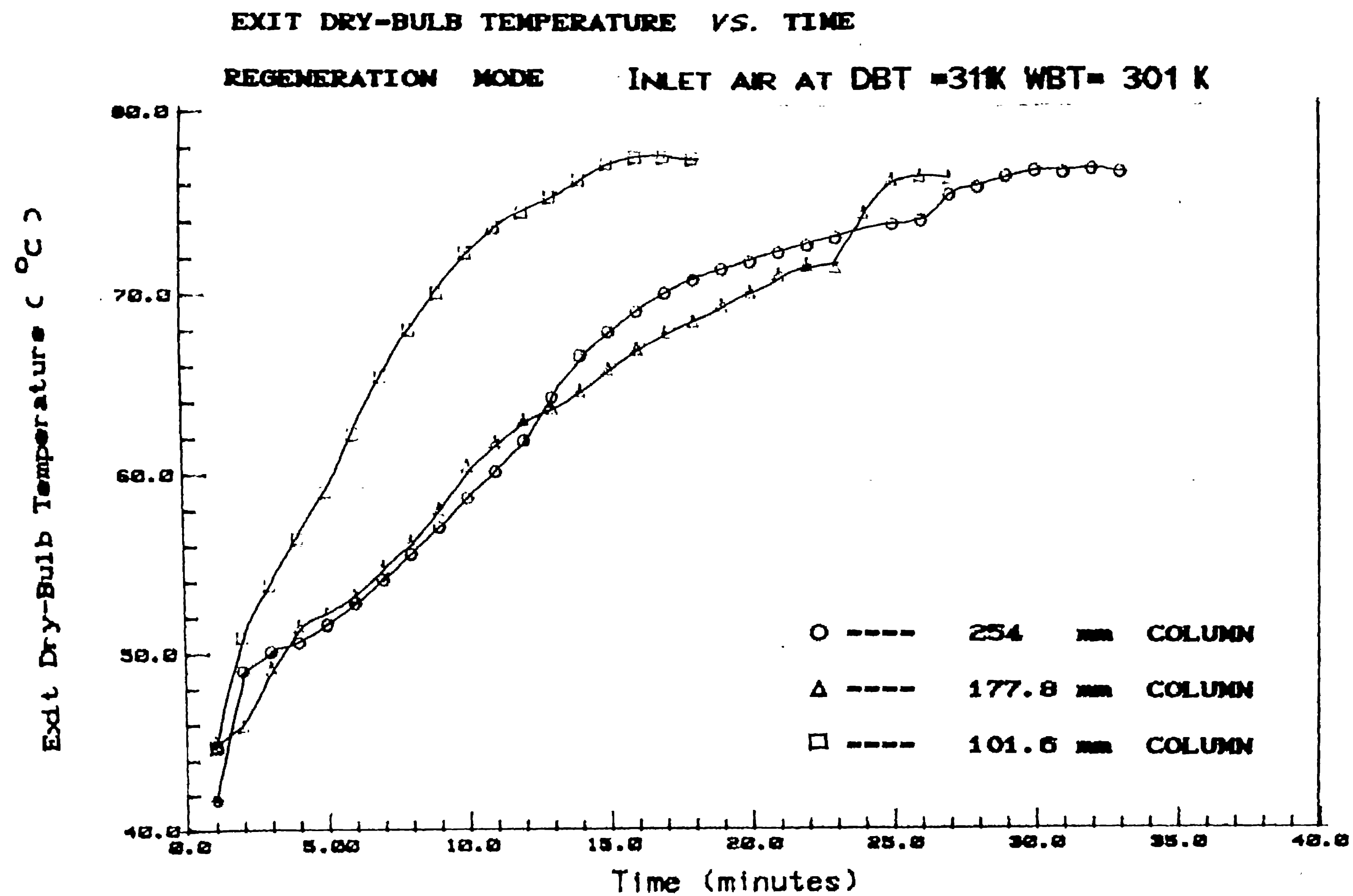

EXIT DRY-BULB TEMPERATURE VS. TIME
REGENERATION MODE
INLET AIR AT DBT =311K WBT= 301 K
Exit Dry-Bulb Temperature (°C)
80.0
70.0
60.0
50.0
40.0
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Time (minutes)
○ ---- 254 mm COLUMN
△ ---- 177.8 mm COLUMN
□ ---- 101.6 mm COLUMN

FIG.4.9

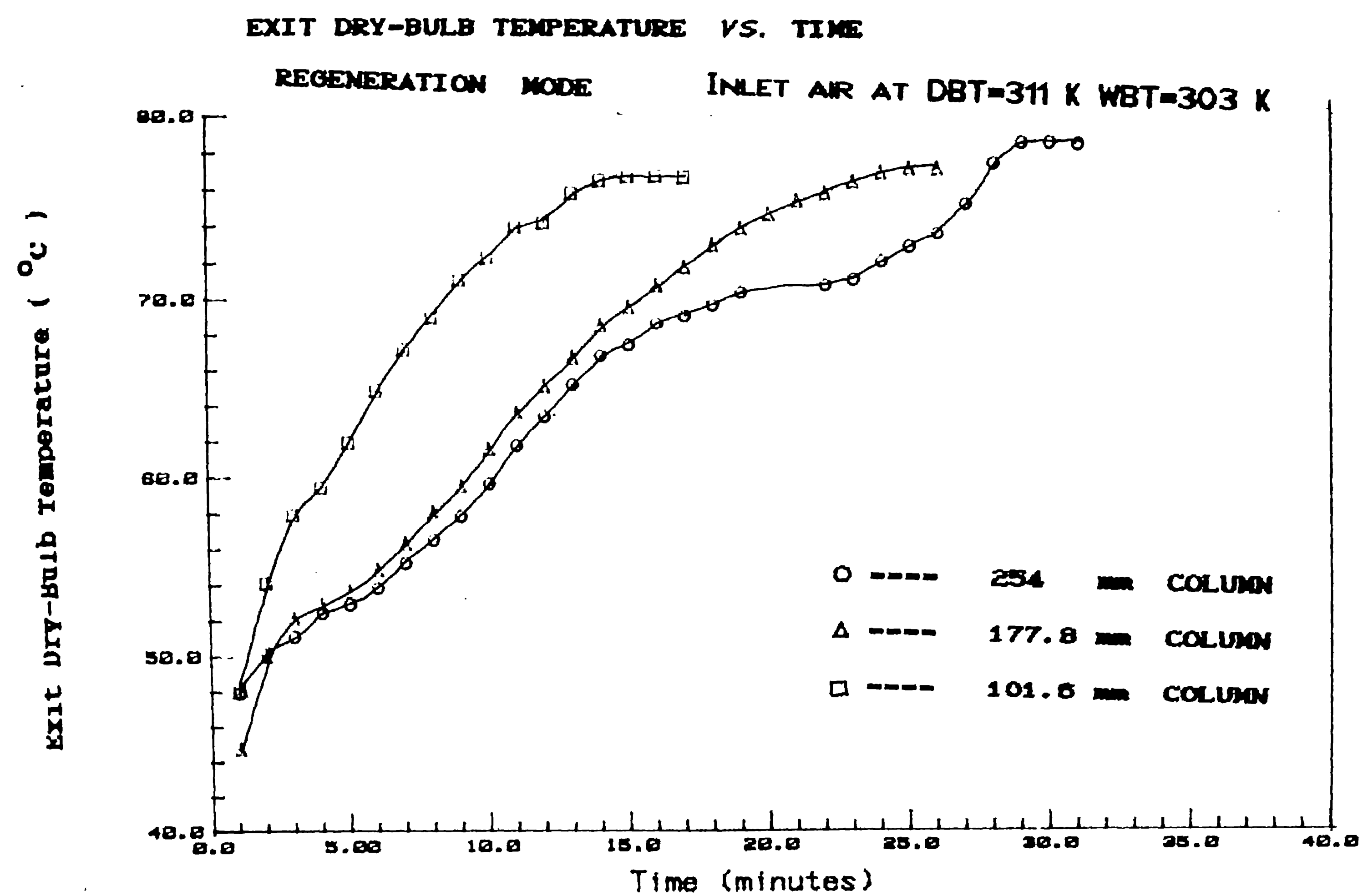

EXIT DRY-BULB TEMPERATURE VS. TIME
REGENERATION MODE
INLET AIR AT DBT=311 K WBT=303 K
Exit Dry-Bulb Temperature (°C)
80.0
70.0
60.0
50.0
40.0
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Time (minutes)
O ---- 254 mm COLUMN
Δ ---- 177.8 mm COLUMN
□ ---- 101.6 mm COLUMN

FIG.4.10

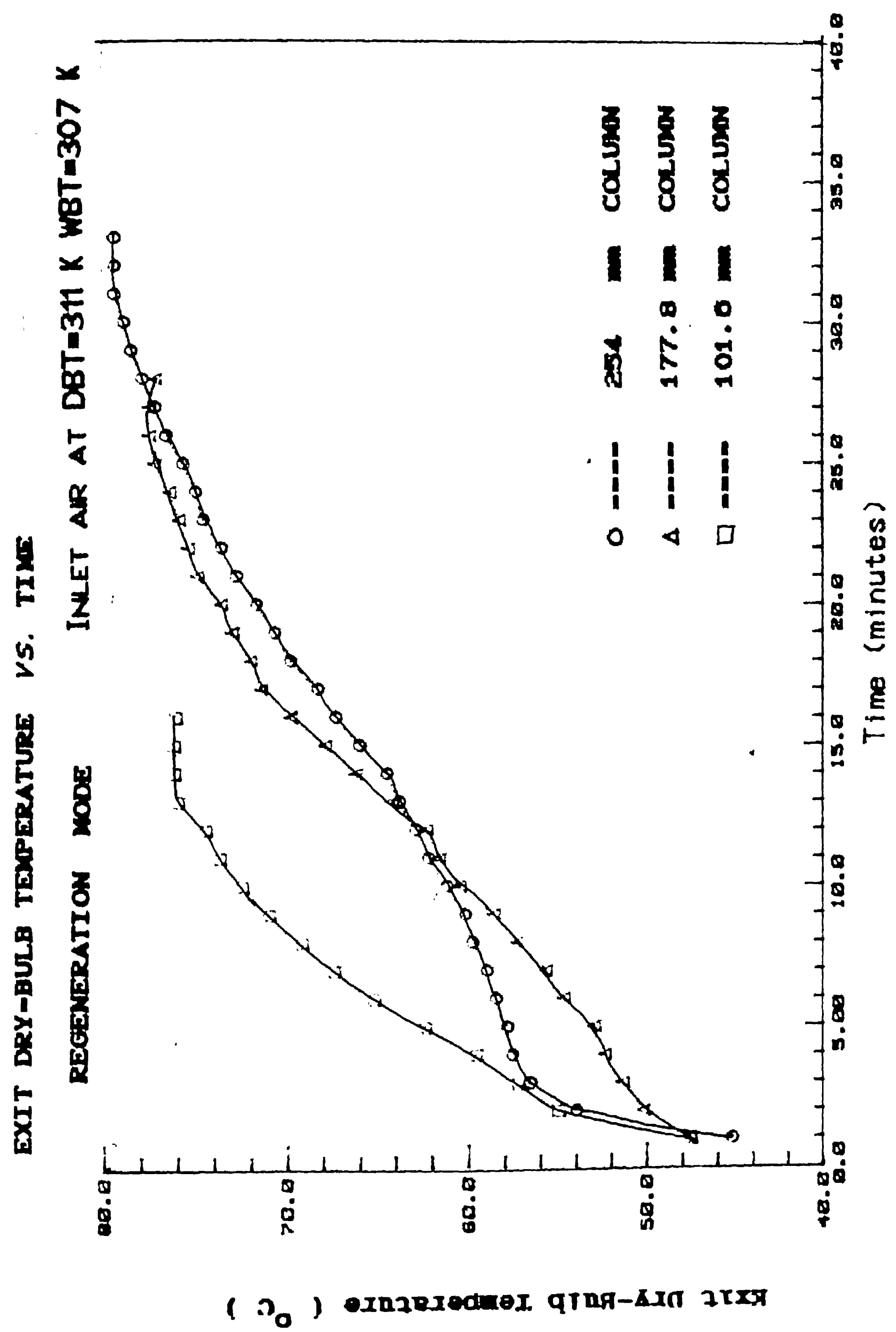
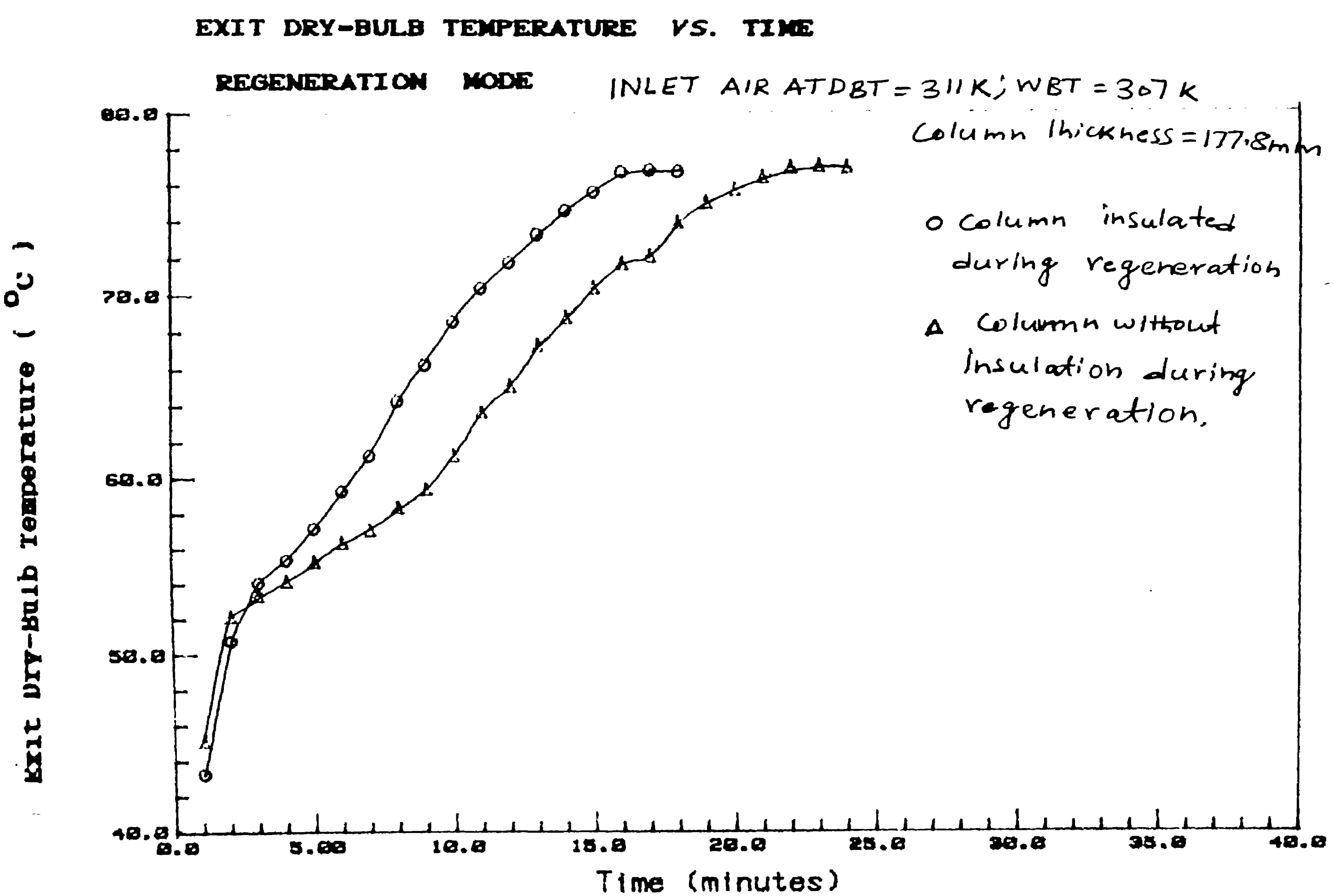

EXIT DRY-BULB TEMPERATURE VS. TIME
REGENERATION MODE
INLET AIR AT DBT=311 K WBT=307 K
○ ----- 254 mm COLUMN
△ ----- 177.8 mm COLUMN
□ ----- 101.6 mm COLUMN
Time (minutes)
Exit Dry-Bulb Temperature (°C)
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
40.0
50.0
60.0
70.0
80.0

FIG.4.11



EXIT DRY-BULB TEMPERATURE VS. TIME
REGENERATION MODE
INLET AIR AT DBT = 311 K; WBT = 307 K
Column thickness = 177.8 mm
o Column insulated during regeneration
Δ Column without insulation during regeneration.
Exit Dry-Bulb Temperature (°C)
80.0
70.0
60.0
50.0
40.0
0.0
5.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Time (minutes)

FIG.4.12

PRESSURE DROP *VS.* BED THICKNESS

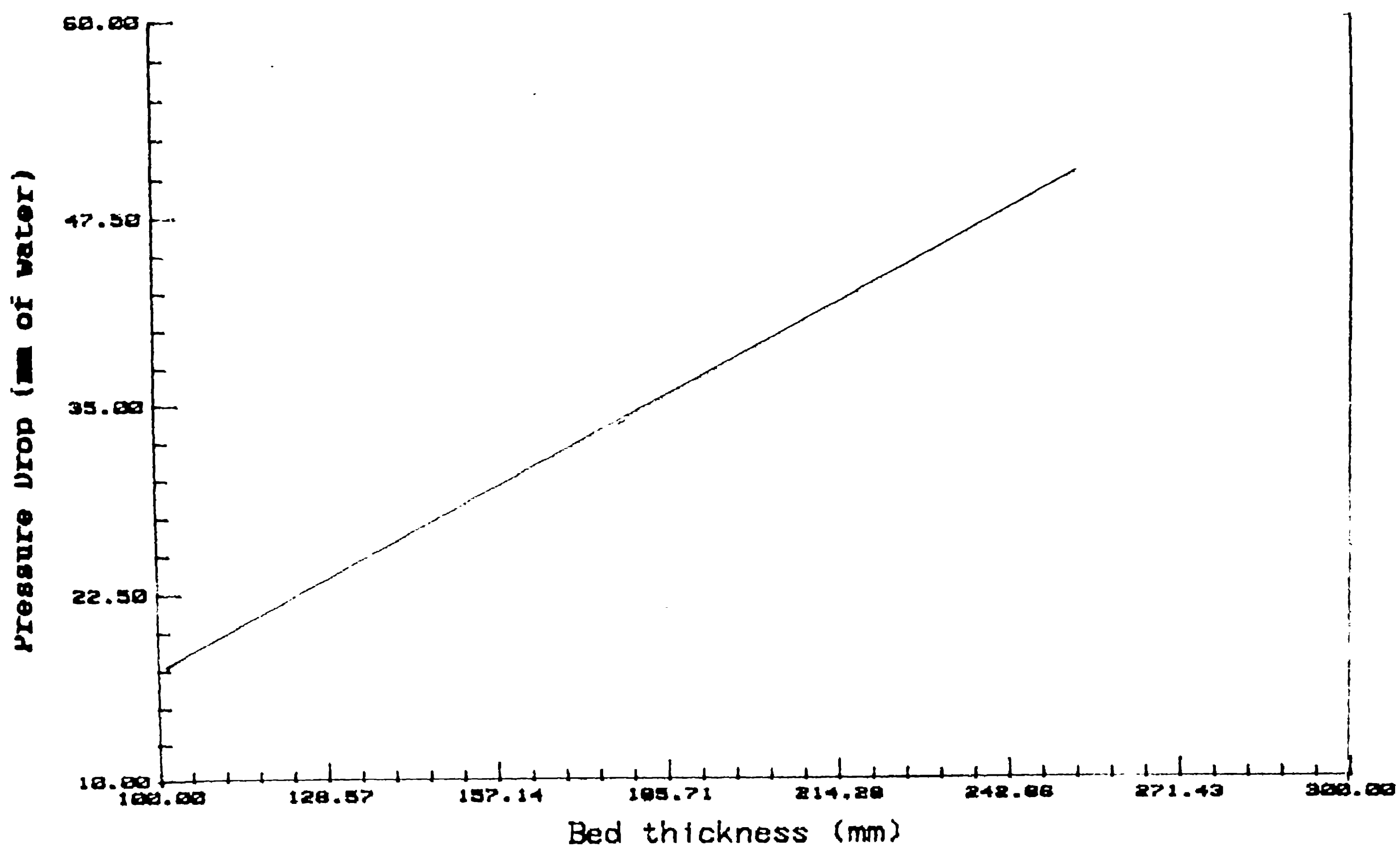


FIG.4.13

TABLE 4.1

SUMMARY OF EXPERIMENTAL RESULTS

1	2	3	4	5	6	
Air Condn.	Bed Thick mm	t_b	$t_{sat.}$	$t_{reg.}$	T_{peak}	1
DBT=311K Wbt=301K	101.6	NO BR.PT.	16	16	49.8	2
-do-	177.8	7	26	24	54.8	3
-do-	254	10	36	32	58.2	4
DBT=311K WBT=303K	101.6	NO BR PT.	15	16	52.8	5
-do-	177.8	6	23	24	56.4	6
-do-	254	8	33	29	59.7	7
DBT=311K WBT=307K	101.6	NO BR.PT.	10	15	56.2	8
-do-	177.8	5	21	25	59.9	9
-do-	254	6	27	31	64.5	10
DBT=311K WBT=307K	177.8	6**	20	22	53.0	11
-do-	177.8	5	22	16*	58.6	12

t_b-- Break Point Time (Minutes)

$t_{sat.}$ --Saturaion Time (minutes)

$t_{reg.}$ --Regeneration Time (minutes)

T_{peak} --Peak DBT of effluent air in dehumidification mode(^oC)

*--Bed was insulated in regeneration mode

**----Bed was cooled in the dehumidification mode

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

5.1 CONCLUSIONS

On the basis of the 22 runs of experiment conducted, following conclusions may be drawn :

1. Below a certain minimum bed thickness, the behaviour of silica gel bed differs significantly from its behaviour with thick beds. For thin beds it does not show any breakpoint. Hence , for any practical system, we must have beds of thickness above this critical value . The critical thickness lies somewhere between 101.6 mm and 177.8 mm. To be on the safer side the critical thickness value may be taken equal to 177.8 mm
2. Thicker beds are found to be superior to thinner beds, hence thicker beds should be used.
3. Cooled beds are found to be superior for dehumidification of air . Besides, the effluent dry-bulb temperature is also lower as compared to an uncooloed bed.
4. Regeneration time of a given thickness of a desiccant bed almost remains constant for inlet air of different relative humidity values.
5. Regeneration time of a bed of given thickness reduces substantially if the desiccant column is thermally insulated.
6. Correlations for regeneration time , saturation time peak temperatures are given in terms of relevant partametwrs.

5.2 SUGGESTIONS FOR FURTHER WORK

1. Similar such study needs to conducted for different particle size of silica gel in order to have much broader scope of getting the

optimum particle size. The finer particles lead to higher pressure drop, but, render improved dehumidification characteristics. Experiments have to be conducted for varying flow rates and different particle sizes. Thereafter, a more generalized correlation may be developed for designing optimum size of bed for a given application.

2. Study should be made for the effect of porosity and surface area per unit mass of adsorbent , on the performance of adsorbent bed.

3. Some other source of thermal energy such as solar, bio-gas or waste heat etc. may be used in order to get actual behavior of the prototype system.

4. A practical system should be studied with different types of cooling of the bed.

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